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CONTENTS

- 41. Development of an infant chimpanzee during her first year.

 CARLYLE F. and MARION M. JACOBSEN and JOSEPH G.

 YOSHIOKA. Pp. 88.
- 42. Studies in concept formation.
 PAUL E. FIELDS. Pp. 70.
- 43. Conditioning finger retraction to visual stimuli near the absolute threshold.

 SIDNEY M. NEWHALL and ROBERT R. SEARS. Pp. 25.
- 44. The organization of learning and other traits in chickens.

 JACK W. DUNLAP. Pp. 55.
- 45. The modification of vestibular nystagmus by means of repeated elicitation.
 - O. H. MOWRER. Pp. 48.
- 46. Mechanisms of handedness in the rat. Geo. M. Peterson. Pp. 67.

DEVELOPMENT OF AN INFANT CHIMPANZEE DURING HER FIRST YEAR

CARLYLE F. AND MARION M. JACOBSEN AND JOSEPH G. YOSHIOKA

Laboratories of Comparative Psychobiology, Yale University

CONTENTS

Foreword by Robert M. Yerkes. Acknowledgments.	1 5
I. Introduction	6
Dietary and adaptation to food	
II. Physical growth.	12
Dentition	
Anthropometrical measurements	
Ossification of epiphyseal centers	
III. Physiological development	20
Original reflexes	
Temperature, pulse, and respiration	
Special conditions	
IV. Behavioral development	40
Introduction	
Cross-sectional summary of behavior	
The motor sequence	
V. Behavioral development (cont'd)	54
Reaching, grasping, and manipulation	
Vocalization	
Emotional behavior	
VI. Behavioral development (cont'd)	71
Play and exploration	
Social behavior	
Chimpanzee and human: The Gesell tests	00
Appendix A	82
Bibliography	88
Plates	89
Index	93

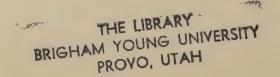
FOREWORD

To present observers and observed in proper perspective and to indicate distribution of opportunity, responsibility, and service, this prologue to an account of the first year of a chimpanzee's life is written by the only member of the staff of the Yale Laboratories of Comparative Psychobiology who has been continuously connected with the work from its inception and who consequently has direct knowledge of all the pertinent circumstances.

As a contribution to psychobiology this monograph is unique, because never before has there been opportunity to write, with reasonable accuracy, the life history of a chimpanzee born of parents of known psychobiological characteristics. In this particular instance it happens that the subject of description has been followed from conception, through a gestational period of nine lunar months, to birth, and thereafter through the period of infancy. Previous records, although apparently similar to this one, actually lack accurate observations on some or all of the following items: time of conception, duration of gestation, birth date, circumstances of parturition, conditions at birth. It is eminently fitting, therefore, to characterize this contribution as significant.

The scientific value of the chimpanzee herein described, number 28 in our institutional series, can best be appreciated in the light of the principal features of the provisions for anthropoid research and of the plan and program which have been developed at Yale University. The institution's Laboratories of Comparative Psychobiology are designed, equipped, and organized primarily for the effective use of primates, and especially of anthropoid apes, in attack on varied problems of life. There are three principal types of constructional provision for research. Of these the first is a well-equipped academic headquarters laboratory in New Haven; the second, a specially designed breeding station in North Florida; and the third, temporary and permanent provisions for naturalistic studies in primate habitats.

The general plan of work of this Yale organization provides that animal subjects shall be bred and reared in the laboratories under as nearly optimal conditions of life as can be maintained; that life history shall be accurately observed and recorded, and that physical, physiological, and psychobiological characteristics shall be measured periodically as basis for description, comparison, and the selection of individuals for special experimental



requirements. This regimen is incidental to and in many respects preparatory for the solution of specific problems.

Work in our New Haven laboratories, then temporarily housed in an old barn, was begun in 1925 with four chimpanzees, taken on faith from the wilds of Africa. The Florida breeding station was established in 1930. Facts concerning our initial supply of animals relevant to the following report may be summarized thus:

NAME	NUMBER	SEX	HYPO- THETICAL BIRTH DATE	ESTIMATED AGE JANUARY 1, 1930
Bill	1	Male	1922	8 years
Wendy	4	Female	1923	7 years
Pan	3	Male	1922	8 years
Dwina	2	Female	1920	10 years

Of the above animals, Pan and Dwina are notable as the parents of the infant Alpha. This individual has the distinction of being the first chimpanzee born in the Yale Anthropoid Experiment Station in Florida. From various points of view she therefore is of peculiar interest and value to our establishment.

These apes were kept and studied in New Haven and at the writer's summer home in New Hampshire from 1925 to 1930, when they were transferred to Orange Park, Florida. For the first two years of the above period the burden of work in the Primate Laboratory was carried by the writer and Doctor Harold C. Bingham, who followed closely the physical and social development of the individuals while also conducting various experimental inquiries. In 1927 Doctor O. L. Tinklepaugh joined us. Whereas it had been Doctor Bingham's privilege and opportunity to study the characteristics of childhood and early adolescence intensively, it fell to Doctor Tinklepaugh's lot to observe sexual maturation and the recurring phases of the reproductive cycle. In 1930 the group of investigators immediately concerned with Pan, Dwina, and Alpha was increased by the addition of Doctor and Mrs. C. F. Jacobsen and Doctor Joseph G. Yoshioka.

¹ For list of Doctor Bingham's relevant publications see *Comparative Psychology Monographs*, 1932, vol. 8, no. 3, p. 22.

To an exceptional degree the work of our laboratories is necessarily cooperative. Partly for this reason it would be unjust to overlook, in publications relative to Alpha, the contributory value of the years of routine care and rigorous scientific observation which prepared the way for the data which are presented in this monograph and also of current reports by Doctor Tinklepaugh. Without the writer probably there would have been no laboratory and no chimpanzees for use; without Doctor Bingham's devoted and skillful care and experimental handling of the animals. Doctor Tinklepaugh's opportunity to study sexual maturation. gestation, and parturition might have failed; and without the work of all three of us in the interest of a program and of objectives which are manifestly over-individual, Doctor Yoshioka and the Doctors Jacobsen certainly would have had no infant Alpha to observe. It is clearly a case for distributed credit, which can more safely and appropriately be described by the Director of the Laboratories than by any other participant in the program of research.

In June of 1929 Doctor Bingham left New Haven for the Belgian Congo and in the same month the writer left for French Guinea. We were both on anthropoid missions which elsewhere have been reported in their scientific aspects. Doctor Tinkle-paugh was left in charge of the New Haven laboratory and the group of four chimpanzees. During his period of responsibility there occurred a succession of developmental events which rendered what might otherwise have been an interval of monotonous routine instead a season of extraordinary and exciting observational opportunity.

Dwina in the spring of 1929 began to show signs of approaching sexual maturity. In May genital swelling first appeared; in September occurred the first menstruation. The sexual maturation of Pan, fortunately for our scientific interests, occurred almost simultaneously with that of Dwina. Although achievement of maturity was not accurately dated, it probably occurred in the spring of 1929. Pan and Dwina on maturing mated, and according to Doctor Tinklepaugh's observations and estimates, as elsewhere reported (see Bibliography, Tinklepaugh, 1932),

Dwina conceived on January 8, 1930. About nine lunar months later (246 days) she bore a large, healthy infant which we naturally decided to name Alpha.

Possibly because of fright and birth shock, for at the time of parturition she was in bad physical condition, Dwina refused to accept and care for her infant. For our scientific purposes this was indeed fortunate, as Alpha was necessarily reared in the nursery of our station laboratory in isolation from her kind. From the first she was bottle fed. The story of her bodily and behavioral development and of the circumstances of her life is engagingly told in the following pages by the authors, whose devotion to Alpha was not a whit less than to their scientific quest.

Throughout the period covered by this report Alpha was continuously available for physical, physiological, behavioral, and other observations and special experiments. Probably no chimpanzee ever has received half the attention that this subject has, and assuredly none has been so painstakingly and thoroughly studied. The quality of this report speaks for itself, but I may appropriately express my admiration of the spirit, method, taste, and judgment of the authors, and my debt of gratitude for their generous and efficient coöperation.

ROBERT M. YERKES.

New Haven, Connecticut, January 15, 1932

ACKNOWLEDGMENTS

In the care of Alpha and in the preparation of the account of her first year of life the writers have had occasion to call on various persons for assistance and advice. We wish to acknowledge our debt and express our gratitude for their generous coöperation and help. The debt to our colleagues in the Laboratories of Comparative Psychobiology is especially great. Professor Robert M. Yerkes has given of his time and experience in the care and observation of the infant, and has critically read the manuscript in addition to furnishing illustrative materials. Dr. Otto L. Tinklepaugh willingly shared the burden of routine care during the first few months, and with one of the writers, J. G. Y., made extensive

behavioral observations at the time of birth and during the first month. He has also furnished illustrative materials. Dr. Henry W. Nissen made available his unpublished observations of two infant chimpanzees which he brought to the Laboratories from French Guinea. Mrs. Helen S. Morford assisted in editing the manuscript. Mr. William C. Atwater lightened the burden of routine care by his assistance in the preparation of food and equipment.

Thanks are due to various practicing physicians of Jacksonville. The staff of the Riverside Hospital gave the use of laboratory and X-ray facilities. Especially heavy is the debt to Dr. Luther Holloway for suggestions on feeding and health, and to Dr. W. M. Shaw for his painstaking coöperation in X-ray examinations.

Colleagues in other fields have rendered this study more complete by contributing from their specialized knowledge: Dr. Helen Thompson, Research Associate, Clinic of Child Development, Yale University, assistance in behavioral analysis; Dr. T. Wingate Todd, director of the Brush Foundation Study, Western Reserve Medical School, and his staff, the examination of X-ray plates and the assessment of Alpha's skeletal development; and Dr. B. Holly Broadbent, Director of the Bolton Study, Western Reserve Medical School, the assessment of Alpha's dental development.

The writers have drawn freely upon the knowledge and experience of these various persons; credit and thanks are extended. Errors in fact or interpretation should be charged to the authors. The conduct and report of this study have been a coöperative undertaking; the main responsibility for the development and preparation of certain portions should be indicated: J. G. Y., the sections on physical growth and physiological maturation; C. F. J. and M. M. J., the introduction and the sections on behavioral development.

Ι

INTRODUCTION

On September 11, 1930, the birth of a female chimpanzee infant, Alpha, no. 28, at the Anthropoid Experiment Station, Orange

Park, Florida, was reported by Dr. O. L. Tinklepaugh. The parents of this animal had been members of the primate colony of Yale University for a number of years. Pan, no. 3, the father, is, at the time of this report, an active member of the colony at the Anthropoid Experiment Station. Dwina, no. 2, the mother, died fifteen days after parturition from puerperal sepsis.²

The illness and death of the mother necessitated placing the infant on a regime of bottle feeding and care at the hands of human attendants, and the following report, consequently, includes a detailed statement of the habitat, dietary, and health, in addition to the accounts of the physical growth and the physiological and behavioral development. The period covered extends from birth through the first twelve months.

Habitat

For the first few days the infant was kept at the Station throughout the twenty-four hours of the day. Practical considerations in the care of the baby, night feedings, temperature control, etc., made it desirable to take the baby to the residences of the staff members in Orange Park. From the fifteenth day through the eighth month the infant regularly spent a part of each day at the Station and was taken to the Jacobsen residence for the remainder of the time. Although the infant spent a large part of her time in the authors' home, no attempt was made "to humanize the ape" through the use of clothes, or by extensive training in the human social graces. From the ninth month until the end of the first year the animal was kept at the Anthropoid Experiment Station.

Living and sleeping quarters. A picnic basket with a hinged cover served as a bassinet for the first three weeks, after which progressively larger corrugated paper boxes were used. A cellucotton pad, covered with rubberized cloth, was placed under the animal. Loose pieces of cellucotton were laid on top of the pad

² At the request of the authors, Professor Yerkes has made a brief statement of the history of Pan and Dwina. His account is found in the foreword to this monograph.

Dr. O. L. Tinklepaugh (1932) has published a detailed account of the gestation, parturition, post-parturition, and death of the mother.

to catch urine and excrement. After the eighth week the infant was kept in a wooden crib, 100 by 60 by 30 cm., built of pine, and mounted on legs 60 cm. above the floor. It was covered with a 1.3 cm. wire-mesh netting, stretched over a semi-cylindrical frame which extended 50 cm. above the top edge of the cage. A solid, hinged door was built into one end of the mesh top and was the only means of access to the crib. At night the wire-net top was covered with canvas in order to maintain a comfortable temperature. Additional warmth was provided by passing the heat from a 50-watt mazda lamp through a 12 by 10 cm. opening in the closed end of the crib.

The use of these cribs was continued until the animal was placed in the adult type of quarters. During the last two months, an inside living room, 2.4 by 2.3 by 3 meters, and an adjoining outdoor cage, 3.1 by 2.5 by 2.2 meters, were provided in a small building detached from the main laboratory and quarters. A description of the physical plant and the organization of the laboratories is given by Yerkes (1932).

Exercise and play. Opportunities for exercise, exploration, and play were determined by the animal's need and ability to use them. In the first two months the infant was handled regularly in the feeding and cleaning routine, and was played with for brief periods several times each day. In the third month she began to explore the sides and floor of the crib, fingered and mouthed projecting parts of the cage, and grasped with hands or teeth the various objects which were offered in the course of tests and experiments.

With the advent of walking at the end of the third month, the animal's environment broadened immensely. At the laboratory she explored the nursery room, examining chairs and tables, measuring instruments, and the miscellaneous objects associated with her care. The much sought nursing bottle had by this time become a favored object, used for play after its contents had been consumed.

At the residence in Orange Park the infant explored all parts of the house most thoroughly, climbed and crawled about the furniture, traced the designs in the rugs with her index fingers, played with rattles, bells, and balls, and examined the miscellary of small objects left within her reach. Outdoors she mouthed and grasped twigs and blades of grass, walked under shrubs, played with sticks, pine needles, and other objects which attracted her attention. The infant made increasingly greater use of these opportunities until the time when she was quartered at the Station throughout the twenty-four hours of the day.

At the Station the infant was provided with an outdoor play cage, approximately 3 by 1 by 1 meters, raised about 30 cm. from the ground. This play cage, which had a solid floor and sides of chicken wire, contained a swing, a climbing ladder or "jungle gym," and an assortment of small wooden blocks. It was situated about 18 meters from the nearest cage of adult animals. The infant used this cage from the eighth month until she was transferred to the adult type of quarters in the eleventh month. In these latter quarters, facilities for climbing, swinging, running, and jumping were available in addition to the blocks and other play objects introduced into the cage.

Companionship. Companionship in the first nine months was very largely limited to the adult humans who cared for and observed Alpha. From time to time after the second month she played with a small dog, and upon three occasions with a thirteenmonth-old human infant. During the tenth month Alpha and Bula, no. 48, a chimpanzee infant from the collection of Madame Abreu, were gradually acquainted with one another. They occupied adjoining cribs in the nursery, but were not brought into direct contact until quartered together during the last two months of the year. An earlier attempt to bring them together had been made, but was abandoned because of the incompatibility of the two strange animals.

Alpha was kept isolated from the adult chimpanzees, with the exception of being in hearing distance of their calls, during the first eight months, and thereafter had opportunity to observe them only from a considerble distance, 18 meters. In the eleventh and twelfth months Alpha and Bula were quartered in a cage adjoining that of four young chimpanzee children.

Dietary and adaptation to foods

Although Alpha was brought up entirely under conditions of artificial feeding, and was never nursed by her mother, her food responses were happily adjusted to the altered regime. A milk mixture based on the Hess formula for human infants was readily accepted, and the later introduction of new foods was accomlished without difficulty. A summary of the infant's dietary is presented in table 1. In this table are shown the number of feedings per day, an estimate in grams of the protein per kilogram of body weight, the estimated total calories per day, and the approxi-

TABLE 1
Dietary summary for infant chimpanzee Alpha

MONTH	NUMBER OF DAILY FEEDINGS	GRAMS PROTEIN PER KILOGRAM BODY WEIGHT	TOTAL CALORIES PER DAY	CALORIES PER KILOGRAM BODY WEIGHT	
1	7	6.2	377	150	
2	7	6.7	529	160	
3	6	6.1	607	145	
4	6	5.8	747	145	
5	5	5.2	769°	130	
6	5	4.9	811	125	
7	4	4.5	811	115	
8	4	4.3	762	105	
9	4	4.1	762	100	
10	4	Anima	al ill; feeding irr	egular	
11	4	2.6	565	75	
12	4	3.5	728	90	

mate number of calories per kilogram of body weight. The values given in the table were based upon representative daily diets, and consequently were subject to minor fluctuations resulting from slight changes in the diet. No attempt was made to determine the degree to which the infant actually assimilated the various foods, hence the values shown in the table represent the amounts of food offered which were from five to fifteen per cent in excess of the actual consumption.

During the first three months the diet was limited to the milk mixture, prepared according to the following formula:³

³ Formula furnished through the kindness of Dr. T. E. Buchman, of Jacksonville, Fla.

	cc.
Water	240
Lemon juice	9
Corn syrup	30
Evaporated milk	

The mixture was further diluted during the first few days, after which it was used in essentially the indicated proportions until the eighth month, when powdered milk, Klim, was substituted for the evaporated, and the amount of syrup reduced slightly more than one half. Starting with an intake of approximately 300 cc. per day in the early weeks, the amount of milk mixture consumed gradually increased until the fourth month when the maximum intake, 720 cc., was reached. During the tenth month when the infant suffered a severe diarrhea, the milk mixture was diluted to varying degrees with barley water. After this illness the use of evaporated milk was resumed.

In the fourth month orange juice and cooked cereal were introduced in the diet. Orange juice, 50 to 60 cc. per day, was accepted from either a cup or spoon, and was taken eagerly when offered in the nursing bottle. The cereals, oatmeal, Cream of Wheat, and Farina, approximately 30 grams per day, dry weight, were consumed readily from the outset. In the fifth month 50 grams per day of puréed vegetables, Gerber's carrots, spinach and peas, were added. Spinach appeared to be the least favored. In the sixth month small amounts of graham cracker, 10 to 20 grams, were included, and occasionally bits of well cooked egg volk were mixed with the vegetables. During the attack of diarrhea the diet was greatly simplified. In the eleventh and twelfth months two new items of food were introduced, banana and Chimcracker, the latter a prepared cracker extensively used in the diet of the older members of the colony (Tinklepaugh, 1931). Throughout the year the per cent of calories derived from protein sources ranged between 13 and 17.

Certain characteristic chimpanzee food responses appeared during the year. By the fourth month Alpha frequently called in a soft guttural bark at the approach of food; and later called vigorously at and before feeding times. Shortly after the introduction of solid foods the infant began to protrude her lower lip, using it as a shelf in the examination of food which had already been accepted. At times food on the lip was wiped off with the forefinger, examined visually, and returned to the mouth. Coprophagy was noted in several isolated instances, although the essential features of the act seemed to be concerned with the oral examination of the feces rather than extensive ingestion.

Disturbances in eating were noted during the period of dental eruption and when the infant suffered from the attack of diarrhea. Sustained thumb sucking before and after meals was seen from time to time during the first three months. Increasing the amount of food offered usually resulted in the disappearance of the activity as long as the food intake appeared to remain adequate.

TT

PHYSICAL GROWTH

Physical growth was studied by dentition, weight, other anthropometrical measurements, and the ossification of epiphyseal centers of the bones as seen on X-ray plates.

Dentition

The time and sequence of dental eruption were noted in our daily records, as each tooth extruded from the gum, and are presented in table 2. It is seen that the first tooth, left upper central incisor, erupted early in the third month; that at the age of three and a half months Alpha had all eight deciduous incisors; that at five months she added the four deciduous first molars, and that by seven months she had erupted the four deciduous second molars. Compared with human dentition, indicated in the last column of table 2, it appears that Alpha's dental development progressed more rapidly and that the sequence of eruption closely paralleled that of humans. If the left upper central incisor had been the third or fourth tooth erupted, instead of the first, the sequence would have been identical with that of humans, except for the canines which did not erupt until early in the second year.

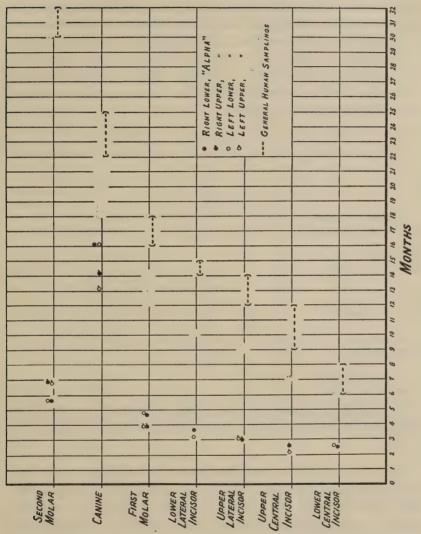


FIG. 1. ERUPTION OF MILK TEETH

Perusal of the data of table 2 shows that Alpha's teeth erupted not only much earlier but in a closer temporal sequence than do the teeth of human infants; thus Alpha completed the eruption of her deciduous dentition between the second and sixteenth months, in contrast to the longer period, six to thirty-two months, required by human infants. On the whole, the order of eruption of Alpha's deciduous teeth was similar to that of healthy human infants except for the reversed sequence of the canines and second molars.

TABLE 2 $Time\ of\ eruption\ of\ milk\ teeth\ expressed\ in\ months\ for\ the\ infant\ chimpanzee\ Alpha^*$

	ALPHA	GENERAL HUMAN SAMPLINGS
Lower central incisors	2.2; 2.5	6-8
Upper central incisors	2.4; 2.5	9–12
Upper lateral incisors	2.8; 2.9	12–14
Lower lateral incisors		14–15
Upper first molars	3.7	
Lower first molars		16-18
Upper canines	13; 14	00.04
Lower canines		20-24
Lower second molars	5.5	
Upper second molars		30-32

^{*} The data of human dentition were supplied by the courtesy of Doctor B. Holly Broadbent, Director of the Bolton Study, Western Reserve Medical School, Cleveland.

Dental development can be studied more reliably by the time and sequence of dental calcification as revealed on X-ray plates. Extrusion of a tooth through the gum is more or less an accidental event: a hard gum may retard extrusion of a sufficiently developed tooth, while a soft gum, or a gum mutilated by rubbing or injury, may expose a less well developed tooth. On the other hand, the time and sequence of the beginning of dental calcification reveal the more intrinsic dental development. Table 3 gives

Alpha's dental age in terms of human calcification standards based on the Broadbent scale. It is seen that at the chronological age of three months Alpha had the dental age of one year and two months for deciduous teeth, and the dental age of six to seven months for permanent teeth. In other words, Alpha's deciduous teeth at three months of age were calcified as completely as the corresponding human teeth at the age of one year and two months; and her permanent teeth were as well developed as human permanent teeth at the age of six to seven months. At the chronological age of twelve months Alpha's dental age for deciduous teeth had advanced to two years and nine months,

 ${\footnotesize \begin{array}{c} {\rm TABLE~3}\\ {\it Dental~development~of~Alpha~expressed~in~terms~of~human~calcification~standards~in\\ {\it months} \end{array} }$

CHRONOLOGICAL AGE	DEVELOPMENTAL AGE OF MILK TEETH	DEVELOPMENTAL AGE OF PERMA				
3	14	6-7				
5	20	10				
6	22	12				
7	26	15				
8	28	16				
9	29	17				
10.5	30	19				
11	32	20				
12	33	21				

and that for permanent teeth to one year and nine months. Here again the accelerated dental development in the chimpanzee was observed.

$Anthropometrical\ measurements$

The weekly weight curve, figure 2, is fairly smooth throughout and conforms in shape to typical growth curves, except for a dip in the first week when food intake was irregular, and for another depression in the tenth and eleventh months when Alpha suffered from summer diarrhea. The initial weight was 2.26 kgm. (4.97 pounds), the heaviest birth weight thus far reported for a chimpanzee. During the first week weight decreased, sinking to the

lowest level on the fourth and sixth days when Alpha weighed 2.02 kgm., having lost 0.24 kgm. (0.53 pound) since birth. She regained her initial weight by the fifteenth day, and thereafter gained rapidly from day to day. The initial weight was doubled in ninety days and trebled in one hundred and eighty-two days.

In further studying the growth rate in weight the average daily gains during a given week were expressed as a function of body weight. The values for this ratio are plotted by weeks in figure

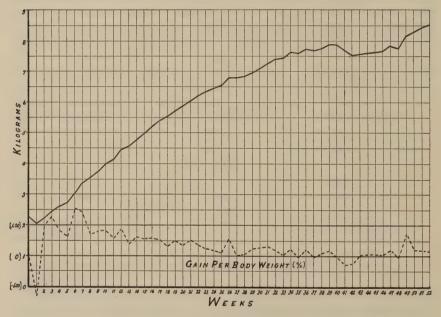


Fig. 2. Weight

2 (broken line). It is seen that in the first week the average daily loss in weight amounted to 1.3 per cent of the body weight. In the second week the loss changed to a gain, and from this time through the eighth week the average daily gain was nearly 1 per cent of the body weight, and thereafter decreased gradually. Averaging these percentage gains by lunar months (four weeks), the following figures were obtained for the first to the fourteenth lunar months respectively: 0.45, 1.09, 0.77, 0.55, 0.42, 0.34, 0.20,

0.28, 0.11, 0.06, -0.11, 0.06, -0.09, 0.33. The gain was greatest in the second month, and decreased thereafter gradually until it became practically zero in the tenth and twelfth months and negative in the eleventh and thirteenth months. In the fourteenth month, however, it rose to the level of the sixth month and maintained itself at that level well into the second year. The period of no gain and negative gain (loss) was probably prolonged due to digestive trouble during the summer months. With this exception the trend of the growth rate from month to month was strikingly similar to that of healthy human infants.

Other anthropometrical measurements, twenty-nine linear measurements, probably indicative of growth determined primarily by hereditary factors, and six girth measurements, reflecting possibly to a greater degree environmental effects, such as nutrition and physiological states, were taken monthly. original data of these measurements and their detailed treatment will appear elsewhere. In order to analyze growth trends through the year these data were treated in the same manner as the weight records. Each measurement was converted into a ratio in terms of the monthly gain over the gross monthly measure. The averages of such ratios by months are given in table 4. seen that the average growth rate was greatest in the second month, next greatest in the third month, while the fourth, fifth and sixth months followed in order. After the seventh the growth rate was less rapid and varied only slightly until the end of the year. A similar trend has already been noted in the growth rate for weight. The standard deviations of the mean growth rates showed a similar trend, i.e., the measurements varied among themselves more widely when growth was rapid than when it was slow. It may be said, therefore, that during the first half of the year, growth was more rapid than during the second half.

The growth rates were converted next into "standard" growth rates in reference to the monthly standard deviations of the means, excluding weight, since it was found to increase at a relatively greater rate than any other measurement. Weight is, in fact, a composite of all other measurements; an increase in each measure contributing to an increase in weight. In terms of

the "standard" growth rates each measurement now became directly comparable with any other measure. Next, the average of these "standard" growth rates was computed, and each measurement ranked in terms of the deviations from the mean "standard" growth rate. The measurement that approached most closely, month by month, to the monthly mean "standard" growth rates was considered the most representative of the general growth process of the body; the measurement that deviated most was considered the least representative. The assessement thus made showed that the following five measurements were most representative: total head height, chest circumference, forearm length, upper face height, and leg circumference; the five least representative: thigh circumference, ear breadth,

TABLE 4

Average monthly growth rates for infant chimpanzee Alpha

	MONTH 1	MONTH 2	MONTH 3	MONTH 4	MONTH 5	MONTH 6	MONTH 7	MONTH 8	момтн 11	момтн 12
Mean rates	5.03	8.50	6.12	5.39	4.12	3.99	2.78	2.51	0.87	2.86
σ										
σ _M	0.524	0.841	0.539	0.487	0.423	0.453	0.340	0.245	0.243	0.430

foot length, chest depth, and neck circumference. Weight was less representative than any one of the thirty-five measures. The significance of these findings and the discussion of reliability of measurement will be considered in a subsequent publication.

Ossification of epiphyseal centers

Growth rates were further studied through an analysis of the time and sequence of the ossification of epiphyseal centers as revealed by X-ray examination. Table 5 presents a summary of these findings, of which a more complete report will be made in conjunction with the anthropometrical measurements. The general trend of these data indicates that the skeletal development of this chimpanzee proceeded rapidly during the first seven months, and slowed thereafter until the end of the year when a

further spurt was shown. It is quite possible that the plateau in the eighth and ninth months, as in the case of weight and other anthropometrical measurements, reflects the digestive disturbance which became acute in the tenth month. It should also be noted that the development of the arms is relatively more advanced than that of the legs. These data are presented graphically in figure 5 in relation to pertinent features of the behavioral development (see motor sequence, p. 52). No attempt is made to give an evaluation of the entire skeleton, since Professor Todd's standards do not at this time permit an accurate assessment beyond thirty-three skeletal months for a female chimpanzee.

TABLE 5 Skeletal age of Alpha expressed in terms of human standards of ossification of epiphyseal centers *

	CHRONOLOGICAL AGE IN MONTHS								
	3	5	6	7	8	9	10.5	12	
Skeletal age in months: Arms Legs	10 5+	17	18 12+	24 24	24 24	24 24	33+ 29-	33+ 29	

^{*} The assessment was made from Alpha's X-ray plates by Dr. T. Wingate Todd, Director of the Brush Foundation Study, Western Reserve Medical School, Cleveland, and his staff, on the basis of Todd's standard scale for human skeletal age.

Contrasted with the development of the human infant, it is to be noted that at the age of three months Alpha's skeletal ossification of the arms was equivalent to that of a ten-month-old human infant, and that the growth of the legs was comparable with that of a five-month-old infant. At seven months the calcification of both the arms and legs was equivalent to that of a two-year-old child, and at the end of the year approached that of a three-year-old child.

In summarizing Alpha's physical growth during the first year the following points are noted:

1. The rate of growth, expressed in dentition, weight, and other anthropometrical measurements, and ossification of the epiphyseal

centers, was more rapid in the first six months than in the last half of the year.

- 2. Compared with healthy human infants the growth rates for Alpha are greatly accelerated. Thus, judged by the standards indicated, the year-old chimpanzee infant had a physical development equivalent to that of two- to three-year-old human infants.
- 3. In the dental and skeletal growth close correspondence to the human infant in sequential development was observed.

TIT

PHYSIOLOGICAL DEVELOPMENT

Physiological maturation was studied by reflexes, by variations in temperature, pulse, and respiratory rates under various conditions, and by other incidental physiological observations. Since our chief aim lay in tracing physiological maturation in relation to behavioral development under normal conditions, no strenuous experimental procedure was introduced, but instead, our study was confined to measurements and observations that left the animal as little disturbed as possible. Hence our investigation deals mainly with the maturation of coördinative function between the circulatory and respiratory systems.

Original reflexes

Eye. Shortly after birth the eyelids were closed in the sun and opened in the shade; the pupils dilated in a weak light, contracted in a strong light. This pupillary contraction, however, was slight on the first day and increased after the first week. Binocular coördination, tested by moving an object, such as a finger or a coin presented within 20 cm. of the eyes, was noted in horizontal, vertical, and oblique directions; it was stronger horizontally than vertically, and stronger vertically than obliquely.

Ear. A hand clap or closing a metal snap above, behind, or to one side of the head, was responded to by trembling of both pinnas, but in no case was the head turned toward the sound. A loud noise made near her basket elicited vigorous generalized movements of the body.

Mouth. Not until the second day were active sucking responses

observed, although the infant had several times closed her mouth about the attendant's finger during the first twenty-four hours. A nursing bottle, presented for the first time on the second day, was sucked poorly, but within two days adequate sucking responses developed. Milk was apparently distinguished from water shortly after feeding began, in that the former was more eagerly taken than the latter. After the first week water was either rejected or taken slowly, and replacement with milk called out an immediate response.

Hands. The grasping reflex was present at birth. An object pressed lightly against the palm was grasped by flexion of the thumb and fingers with only slight tendency toward thumb-finger opposition. Alpha could sustain herself in the air with one hand for over a minute and for a longer time with both hands.

Feet. The feet responded similarly to the hands in grasping and in suspension in the air. The great toe flexed and opposed more effectively than the thumb. The extensor thrust was present, but the Babinski reflex was absent.

Other general observations. With the exception of the face, anal and urogenital regions, and belly, the body was covered with black hair. The anterior fontanel was open at birth, but the posterior fontanel was nearly closed. Immediately after birth the scalp over the coronal suture was infolded, probably due to compression during the delivery; this fold disappeared within two The face appeared cynotic; body temperature was low (she was delivered on a concrete floor); pulse was rapid, shallow, and irregular; and respiration was likewise rapid and highly variable. The heart and respiratory sounds were normal for a newborn. Birth-cries were shrill and strong. In the basket the infant's usual posture was to lie on her back with the arms folded over the chest or spread out on the sides, the hands above the head, and the legs drawn up against the sides of the abdomen, frog fashion (see plate 1, upper figure). She kept this posture more or less constantly until she began to move about. A touch on any part of the body elicited a general response of all parts of the body somewhat like a strychnin convulsion. This diffused type of response was gradually replaced by a more localized response as she matured. Temperature sense was present to the extent that a touch with a wet towel rinsed out of water colder than 20°C. or hotter than 70°C. elicited a vigorous protest. The meconium began to be discharged on the second day, and by the fourth day it had completely passed out.

Therefore it may be said that Alpha possessed most of the basic reflexes of sense organs and of locomotion at birth, and it is further noted that during development functional coördinations among these equipments gradually appeared so that her responses changed in character from a diffused and generalized type to a localized and specific type.

Temperature, pulse, and respiration

Temperature. A comparative study between the axillary and rectal temperatures was made with Alpha and four older animals, and it was found that in these animals the axillary temperature registered higher and was more constant than the rectal temperature, due to the anatomical peculiarity that the rectum is more exposed to the air and hence subject to more rapid heat radiation than the axilla which is protected by hair.⁴ In the following discussion axillary temperatures are referred to unless the rectal temperature is specified.

The mechanism of temperature regulation was functioning poorly at birth, and the body temperature in the early days varied with the changes in the surrounding temperature. When Alpha was lying on the concrete floor immediately after birth, the temperature was 36.0°, rose to 36.9° when she was placed on a Turkish bath-towel in her basket, and later fell to 35.9° in the evening. During the next two days the temperature remained around 36.0° and thereafter rose to a higher level, fluctuating around 37.0° (98.6°F., human normal).

In these early days an exposure to direct sun for ten to thirty minutes would raise the temperature by 0.5° to 1°C., and on the other hand an exposure to a cold draft would lower it as much.

⁴ A more detailed account of the comparison between the axillary and rectal temperatures will appear elsewhere.

For example, on the sixth day, with an external temperature (shade) of 33.0°, she was placed in the sun, resulting in a rise from 36.6° to 37.1°, at which time she appeared prostrated and showed other incipient symptoms of heat hyperpyrexia. Again, on the twentieth day, with an external temperature (shade) of 34.0°, she was exposed to the sun, with a resultant rise in temperature from 37.0° to 37.9° and the appearance of other distress symp-

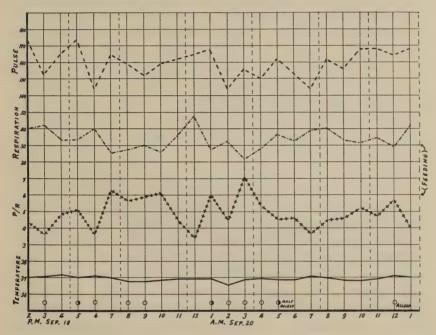


FIG. 3. DIURNAL PHYSIOLOGICAL RHYTHM

toms. On the forty-sixth day, when the external temperature in the shade was 32.0°, a half hour exposure in the sun caused neither a rise in temperature nor other symptoms of hyperpyrexia. By this time her temperature regulatory mechanism had matured sufficiently so that she was no longer at the complete mercy of fluctuating external temperatures. See Nissen (1931, p. 31).

Between day and night her temperature varied 0.5°C. on the average. The solid line in figure 3 shows the hourly temperature

variations occurring on the ninth day during a 24-hour period when she was kept indoors so that the surrounding temperature remained relatively constant. It is seen that the highest temperature (37.2°) was registered at 12 noon and again at 3 p.m., and the lowest (36.6°) at 2 a.m. The diurnal rhythm of temperature had been established at this early date.

The monthly variation in temperature is demonstrated by the monthly mean temperatures and their respective standard deviations obtained from the daily measurements taken at 11 a.m. under normal conditions. From a series of measurements it was found that the temperature at 10-11 a.m. and again at 2-3 p.m. approximated most closely the mean temperature of the day and was used as the most representative. In computing the monthly means the measurements taken at 11 a.m. under normal conditions were exclusively employed; those obtained when Alpha was resistant during measurement or abnormally active previous to measurement were treated separately. These monthly means and their respective standard deviations are given in table 6. It is seen that the mean temperature began at the level below the human normal of 37° in the first month (36.85°), rose steadily until the fourth month (37.30°), dropped slightly in the next two months, reached the highest peak in the seventh month (37.35°), dropped again in the eighth, ninth, and tenth months, and picked up again in the last two months of the year (37.30° and 37.27° respectively). The monthly fluctuation is shown graphically in figures 4a and 4b. Possible factors influencing these fluctuations are enumerated. Climatically the third and fourth months were the coldest; the ninth, tenth, and eleventh the hottest. From the third to the seventh month, when the body temperature remained above 37°, the teeth were erupting. Hence neither seasonal temperature changes nor dental eruption are adequate to account for the fluctuations obtained. Toward the end of the first year the body temperature tended to reach a level comparable to that of the two- to four-year-old animals in our colony. The variability in the mean temperatures expressed by the standard deviations was the greatest in the first month (0.58) and decreased gradually toward the end of the year (0.22 in the twelfth

month), though there was a slight inversion of the order in the fifth and seventh months.

TABLE 6

Monthly variations in pulse rate, respiratory rate, and body temperature for the infant chimpanzee Alpha

PULSE RATE RESPIRATORY RATE P/R* TEMPERATURE										
	NUMBER OF	PULSE	RATE	RESPIRATO	ORY RATE	P/	'R*	TEMPE	RATURE	
MONTHS	MEASURE- MENTS	Mean	σ	Mean	σ	Mean	σ	Mean	σ	
1	28 {	161.64 4.189		43.14 1.940	10.26 1.372	3.89 0.149	0.79 0.106	36.85 0.110	0.58 0.078	
2	31 {	185.71 1.845		56.00 1.632	9.09 1.155	3.36 0.104	0.58 0.074	36.97 0.054	0.30 0.039	
3	26 {	174.50 2.178	11.11 1.541	60.19 1.823	9.30 1.290	2.96 0.076	0.39 0.054	37.13 0.057	0.29 0.040	
4	28 {	161.25 2.297	12.15 1.624	56.79 0.879	4.65 0.621	2.85 0.061	0.32 0.043	37.30 0.047	0.25 0.033	
5	29 {	162.52 2.673	14.41 1.891	60.59 1.497	8.07 1.059	2.72 0.085	0.46 0.060	37.24 0.067	0.36 0.047	
6	26 {	153.19 1.927	9.83 1.363	54.12 1.133	5.87 0.818	2.86 0.080	0.41 0.057	37.28 0.057	0.29 0.040	
7	25 {	145.32 1.872	9.36 1.324	47.28 1.342	6.71 0.949	3.12 0.092	0.46 0.065	37.35 0.069	0.34 0.049	
8	29 {	142.31 1.583	8.53 1.119	40.72 0.887	4.78 0.627	3.53 0.072	0.39 0.051	36.95 0.043	0.23 0.030	
9	10	138.30†		40.60		3.43		36.95		
11	15	136.60†		37.73		3.55		37.30		
12	29 {	133.66 1.212		37.41 0.605	3.26 0.428	3.60 0.052	0.28 0.037	37.27 0.041	0.22	

^{*} P/R = ratio of pulse rate to respiratory rate. Sigmas are indicated immediately below each value.

Summarized, Alpha's physiological maturation as reflected by body temperature manifested itself in (1) early establishment of

[†] No standard deviations were computed due to too small a number of cases.

diurnal rhythm, (2) gradually increasing efficiency of the regulatory mechanism as noted (a) by the decreased influence of external temperature and (b) by the decrease in daily variability, and (3) the tendency to approach the temperature level of older animals.

Pulse rate. The pulse rate herein reported is the apex beat per minute taken with the stethoscope in the early days and later by palpation when Alpha began to pull on the tubing of the stetho-

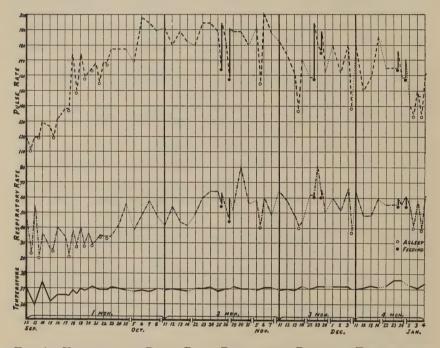


Fig. 4a. Variations in Pulse Rate, Respiratory Rate and Temperature

scope. The radial or femoral pulse was counted at times when she was excessively active, though an arm or leg was apt to move during the measurement, and if pressure were applied to hold the member still, the muscles contracted and hence rendered the pulse less distinct.

At birth and in the early days the pulse was rapid and highly variable. Excitement or external stimulation frequently resulted in an increase of 50 beats within a few minutes, although it was

not observed to decrease the rate. The slowing of the heart due to vagus inhibition under excitement noted in older animals was apparently absent. The pulse rates, obtained daily at 11 a.m. simultaneously with the temperature, were averaged by months and are summarized in table 6. It is seen that the mean monthly pulse rate was high in the first month (161.64), reached a peak in the second month (185.77), and thereafter decreased gradually

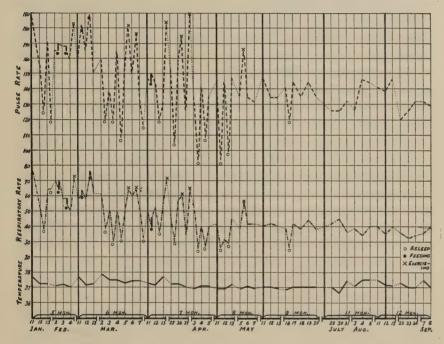


Fig. 4B. Variations in Pulse Rate, Respiratory Rate and Temperature

toward the end of the year (133.66 in the twelfth month). In the fifth month there was a slight inversion of the order. This trend is shown graphically in figures 4a and 4b. With decrease in rate the pulse became more forceful, indicating that the heart had increased in size and in contractile force, which is determined primarily by the initial length of the muscles.

The variability expressed by the standard deviations followed more or less a course similar to the mean rates; it was highest in the first month (22.16), half as high in the second month (10.26), increased toward the end of the fifth month (14.41), and thereafter decreased steadily (6.53 in the twelfth month). Thus the physiological maturation is reflected in the more stable coördination between excitatory and inhibitory innervations of the heart resulting in decreased variability in pulse rate.

Therefore it may be said that Alpha's physiological maturation as noted in pulse consisted in (1) gradual decrease in rate and increase in force, and (2) decrease in variability indicating establishment of a stable coördination between the two antagonistic innervations of the heart.

Respiratory rate. The respiratory rate is the rate per minute taken by palpation over the hypogastrium. Since the respiration was abdominal, either palpation or visual method could be applied satisfactorily. Even in the early days crying was relatively inferquent and of short duration when it appeared, hence normal respiratory rates could be obtained easily and frequently.

In the early days respiration was rapid and variable. Under excitement the rate was observed to increase frequently, and on fewer occasions to decrease when respiration became so deep that the total ventilation per minute probably remained relatively constant. The respiratory rates taken daily at 11 a.m., simultaneously with pulse rates, were averaged by months and are given in table 6. It is seen that the mean respiratory rate was relatively low in the first month (43.14), reached a peak in the fifth month (60.19), and thereafter decreased steadily toward the end of the year (37.41 in the twelfth month). There was a slight inversion of the order in the fourth month. The general trend is shown graphically in figures 4a and 4b. The monthly fluctuation was more varied than that of the pulse. It is to be noted that normal respiration is initiated by an impulse from the respiratory center in the medulla, but its rate is mechanically determined by two major factors; the size of the thoracic cavity and the strength of respiratory muscles. Consequently a stable decrease in rate can be expected only after these two factors have developed proportionally.

The variability expressed by the standard deviations was high

in the first month (10.26) and declined gradually toward the end of the year (3.26 in the twelfth month), indicating a more stable control of respiratory activities. An inversion of the order was noted in the third, fifth, and seventh months. Therefore it may be said that Alpha's physiological maturation as noted in respiration was essentially the same as that seen in pulse and showed a gradual decrease in rate and variability.

Ratio of pulse rate to respiratory rate. The ratio of pulse rate to respiratory rate, designated here by P/R, was computed in order to learn the nature and degree of functional dependence between the circulatory and respiratory systems. The heart and lungs can be considered structurally as elements possessing elastic properties in a closed system of fluid conduit, and hence the functional coördination between them is essentially a problem of hydrodynamics. Applying therefore Bernoulli's theorem which states that the velocity of fluid in a conduit is inversely related to the cross-sectional area of the conduit, it is inferred that more blood passes per unit of time through the heart, which is smaller, than through the lungs, which are larger, and hence the propulsion of the former has to be more frequent than that of the latter, and further, the ratio between the two rates has to be constant in order to maintain a continuous and constant flow of the blood. In other words, it is theoretically necessary that high pulse rates accompany high respiratory rates; that low pulse rates go with low respiratory rates; and that the ratio between the two rates remain constant with changes in the absolute values of the two variables. We shall see how well this theoretical consideration describes our findings.

The ratios computed from the daily pulse and respiratory rates and averaged by months are given in table 6. The ratios were relatively constant throughout the year. The highest mean ratio of 3.89 occurred in the first month and the lowest of 2.72 in the fifth. During the first month the pulse rates were relatively high, while the respiratory rates were relatively low, and hence the ratios were high. During the third to sixth months the reverse conditions prevailed, and the relatively low pulse rates accompanied by the relatively high respiratory rates made the

mean ratios low. Toward the end of the year the ratios tended to be higher. This tendency may be considered as indicating progressive steps in maturation, since four older animals between two and four years of age tested simultaneously with Alpha showed mean ratios of 4.2 to 4.7.

The variability in the ratio expressed by the standard deviations showed a gradual decline from the first month (0.79) to the twelfth (0.28). Typical variability in the first month is shown graphically in figure 3 (crosses). A small variability in the ratio signifies that a change in pulse rate is accompanied most efficiently by a corresponding change in respiratory rate, and hence the decrease in variability shown above indicates maturation of coördinative mechanisms between the heart and lungs from lesser to greater efficiency.

Considering marked anatomical differences between the heart and lungs, such as tissue derivation, innervation, and motor mechanism, the theoretical postulation of the systems set forth in the beginning of this section describes fairly well the functional relationship obtained from actual measurements. Pulse and respiratory rates appear to be functionally coördinated by some basic mechanical principles, and the ratio between the two and its variability may serve as indices of efficiency of the heart-and-lung coördination. Similar studies with older chimpanzees, dogs, and humans support this view.

Comparison of temperature, pulse rate, respiratory rate, and P/R ratio. That all the measurements were more variable in the first month than in any other month is shown in table 6. In the first month the mean pulse rate had a value about seven times the sigma of its distribution, the mean respiratory rate about four times, the mean P/R about five times, and the mean temperature about sixty-four times. Evidently temperature was the most constant of all, pulse rate was next, followed by P/R and the respiratory rate in order. Setting P/R aside for the present because it was derived from pulse and respiratory rates, the order of constancy just mentioned is also the order of reliability of the measurements. The temperature is not only more stable intrinsically but it can be measured more reliably because ther-

mometer reading is more reliable methodologically than counting pulse or respiratory rates by palpation. Between pulse and respiratory rates the former involves smaller errors of measurement than the latter, because for every count of respiration about four heart beats can be counted, and hence one miscount of failure to discard a fraction at the end of one minute for heart beats affects the true value less seriously than a similar error does respiration. If attenuation due to errors of measurement be properly corrected in the obtained values, there may not be much difference in stability between the mean pulse and respiratory rates. We may say then that temperature is more stable than either pulse or respiratory rate, and that pulse rate tends to be slightly more stable than respiratory rate. Now coming to the twelfth month it is seen that the mean pulse rate was twenty times, the mean respiratory rate eleven times, the mean P/R thirteen times, and the mean temperature one-hundred-sixty-nine times, as large as each respective sigma of the distribution. Compared with the similar figures computed for the first month, these four items increased in stability 2.85, 2.75, 2.60, and 2.64 respectively by the twelfth month. Hence it may be said that all the measurements under consideration increased nearly equally in stability during the year.

The stability of the four items was compared in another way. The monthly sigmas of the mean pulse rate, respiratory rate, P/R, and temperature were intercorrelated, and the coefficients are given in table 7.

It is seen that the highest correlation (0.792) was found between the sigmas of temperature and of P/R, the next highest (0.766) between the sigmas of pulse and of respiration. The correlation between the sigmas of temperature and of pulse and that between the sigmas of temperature and of respiration were not significantly high, but between the two, the former (0.612) was slightly higher than the latter (0.539). The sigmas of P/R and those of either pulse or respiration were not correlated because the paired items were not independent variables. These results are highly significant in that they indicate a striking parallel in the functional development of two relatively independent basic physiological

mechanisms, namely temperature control and coördination of pulse-respiratory function.

Special conditions

Pulse and respiratory rates during sleep. Normal sleeping conditions were more difficult to obtain than normal waking conditions. A mere observation of closed eyes and motionless body gave no insight into the depth of sleep, particularly in the early months when Alpha was apparently asleep most of the time. The measurements taken when she was found asleep previous to

TABLE 7 Correlations between the variabilities in pulse rate, respiratory rate, P/R ratio, and temperature

VARIATES	r	t	PROBABILITY
$\sigma_{ m p}$ vs. $\sigma_{ m R}$	0.766	3.153	2
$\sigma_{\rm P}$ vs. $\sigma_{\rm T}$	0.612	2.046	10
$\sigma_{\rm R}$ vs. $\sigma_{\rm T}$	0.539	1.671	20
$\sigma_{\rm P/R}$ vs. $\sigma_{\rm T}$	0.792	3.432	1

 $\sigma_{\rm P}={
m standard}$ deviation of mean monthly pulse rates during a period of nine months. The other sigmas are those of respiratory rate (R), ratio of pulse rate to respiratory rate (P/R), and temperature (T).

$$t = \frac{r}{\sqrt{1-r^2}} \cdot \sqrt{n'-2}$$
. (See R. A. Fisher's Statistical Methods for Research Workers, 1928, Oliver and Boyd, London, p. 159.)

the measurement, when she showed no sign of disturbance during the measurement, and when she continued to sleep after the measurement, were considered as representative of sleeping conditions, are averaged by months, and are presented in table 8.

It is seen that the monthly mean pulse rates during sleep followed a similar course to those during waking hours, starting high in the first month (148.76), reaching a peak in the second month (159.75), and thereafter steadily declining (105.00 in the eighth month). The monthly mean respiratory rates during sleep distributed themselves similarly; from the level of the first month (31.00) there was a rise in the second month (47.50),

followed by a steady decline thereafter (28.40 in the eighth month). The variability in both rates decreased from the first to the eighth month.

The differences in rates between waking and sleeping hours were many. It is noted in comparing the figures in table 6 and table 8 that the level of pulse rates during sleep was on the whole lower than that in waking hours. Similarly respiratory rates in sleep were lower. The differences in the monthly mean pulse rates between sleeping and waking hours for each respective

TABLE 8

Variations in pulse rate and respiratory rate during sleep

	NUMBER OF	PULSE RATE		RESPIRATORY RATE		P/R*	
MONTHS	MEASURE- MENTS	Mean	8†	Mean	. 8	Mean	8
1	21	148.76	17.16	31.00	6.51	4.96	0.93
2	4	159.75	10.21	47.50	8.54	3.45	0.68
3	18	153.22	10.86	44.28	6.91	3.53	0.37
4	11	140.82	9.07	40.36	3.25	3.50	0.37
5	9	124.33	4.54	35.33	3.20	3.57	0.34
6	11	117.82	6.69	32.09	3.84	3.72	0.39
7	16	106.75	7.39	27.63	3.05	3.89	0.34
8	5	105.00	8.55	28.40	3.29	3.74	0.49

^{*} P/R = ratio of pulse rate to respiratory rate.

month from the first to the eighth are as follows: 12.88, 25.96, 21.28, 21.67, 38.19, 35.37, 38.57, 37.31. Similar differences in the monthly mean respiratory rates are as follows: 12.14, 8.50, 15.91, 16.43, 25.26, 22.03, 19.65, 12.32. This difference in the levels is shown graphically in figures 4a and 4b, where the points marked by a circle indicate the measurements obtained during sleep on the days specified by the ordinates to the left of them. It is seen that in the first month the levels of pulse and respiratory rates in sleep respectively were not very much lower than those in waking hours. In figure 3, where the hourly measurements during a twenty-four-hour period on the ninth day are given,

[†] $s^2 = \frac{1}{n'-1} \sum (x-\bar{x})^2$. (See R. A. Fishers's Statistical Methods for Research Workers, 1928, Oliver and Boyd, London, 105.)

both pulse rates (broken line) and respiratory rates (dots and dashes) varied as much in sleep as in waking hours. It is further seen that from the first to the fourth month the monthly differences tended to increase, and in the fifth month showed a big increase, reaching a new high level which was kept nearly unaltered in the remaining months. Behaviorally Alpha showed a big change in the fifth month since by this time she had begun to walk, run, and climb actively. From this time onward her waking conditions differed physiologically from her sleeping conditions more widely than before, and this differentiation was reflected upon pulse and respiratory rates as shown above.

Among other differences the following should be noted. The monthly fluctuations of both pulse and respiration in sleep were smaller and smoother than those in waking hours. Both the monthly mean pulse and respiratory rates reached a small peak in the second month and thereafter declined steadily. The variabilities in both pulse and respiration were less in sleep than in waking hours, although those in sleep were expressed by s which gives a larger value than σ for the same number of cases. P/R ratio was more constant in sleep (3.45–3.89) than in waking hours (2.72–3.53).

It has been mentioned that only in later months were the physiological states differentiated distinctly during waking and sleeping hours. The pulse and respiratory rates taken when Alpha was awake and normally active during the sixth to eighth month (107 observations) were averaged and compared with the averages of those taken when she was in deep sleep (28 observations) during the same period.

The mean pulse rate in waking hours (147.27 ± 1.163) was much higher than that in sleep (107.79 ± 1.550) , and their respective sigmas were similarly different (12.03 ± 0.822) and 8.20 ± 1.096). The mean respiratory rate was likewise higher in the waking state (47.54 ± 0.908) than in sleep (28.64 ± 0.739) , and their respective sigmas were similarly different (9.39 ± 0.642) and 3.91 ± 0.523 . The P/R ratio was lower in waking hours (3.18 ± 0.046) than in sleep (3.88 ± 0.093) , due to the fact than in sleep pulse rate decreased relatively more than respiratory rate.

The differences in each pair of the items compared were all statistically significant, except the sigma of P/R which was almost identical in both states (0.48 and 0.49). In other words, the basic mechanism of coördination between pulse and respiration appears to function as well in sleep as in waking hours. This supports the view already set forth that the P/R ratio and its variability are fairly reliable indices of the basic physiological mechanism of coördination between heart and lungs.

Pulse rate and respiratory rate in activity. It has been shown that pulse and respiration decelerate in sleep. The opposite phenomenon, acceleration of pulse and respiratory rates in various activities, will next be considered.

Feeding. One of the daily activities manifested very early in life was sucking; the infant adapted well to the nipple and bottle and nursed with great vigor. During the first month, however, her milk intake at each feeding was irregular and hence the physical effort expended in sucking at each feeding was relatively inconstant. However, by the second month nursing had become one of the most constant, major activities manifested from day to day, and during this month special measurements of pulse and respiratory rates before and after a feeding were inaugurated. The results are given in table 9.

The means were computed only from the measurements taken when she emptied a given bottle without hesitation or interruption. A bottle containing 120 cc. of milk preparation was consumed in about two minutes. It is seen that the both the post-feeding pulse rate and respiratory rate were accelerated. The differences between the pre- and post-feeding mean pulse rates in each respective month from the second to the seventh are as follows: 16.71, 18.21, 8.26, 4.13, 6.76, -1.98. Similar differences in the mean respiratory rates in each respective month from the second to the seventh are as follows: 8.06, 6.79, 5.14, 3.69, 5.10, 1.25. These accelerations are shown graphically by vertical strokes with circles in figures 4a and 4b. Greater differences were noted in the early months than in the later months, and by the eighth month, when these special measurements were discontinued, the difference had disappeared entirely, although in these

TABLE 9 V ariations in pulse rate and respiratory rate during feeding

			PUISE RATE	RATE			RESPIRAT	RESPIRATORY RATE			P/	P/R*	
A M	NUMBER OF MEASURE- MENTS		Before	After	ter	Bef	Before	After	er	Bef	Before	FF	After
, ,		Mean	ь	Mean	6	Mean	٥	Mean	b	Mean	ь	Mean	ь
	44	178.09	11.11	194.80	7.96	58.89	8.52	66.95	4.57	3.04	0.33	2.93	0.25
	52	174.62	9.95	192.83	6.78	60.40	4.98	67.19	4.93	2.92	0.26	2.89	0.23
	34	163.06	11.53	171.32	9.71	57.74 0.852	4.97	62.88	5.51	2.83	0.24	2.74 0.046	0.27
			100		00		60		90		00		60
	23	163.83	15.11	167.96	11.59	60.83	9.90	64.52	7.36	2.74	0.37	2.61	0.43
	21		11.94		11.90		06.9		8.24		0.37	2.76	0.35
	∞	151.23	3.51	149.25	8.60	46.75	7.32	48.00	7.11	3.29	0.48	3.16	0.46

* P/R = ratio of pulse rate to respiratory rate.

(See R. $\sum (x - \bar{x})^2$. † Variations of the means from the fifth month on are expressed by s defined as s2 = Fisher's Statistical Methods for Research Workers, 1928, Oliver and Boyd, London, 105.) later months Alpha was taking more milk (180 cc.) per feeding. The slight tachycardia and hyperpnea in the act of sucking in the early months were indicative of physiological inadequacy in meeting the demand of the physical labor, and such inadequacy was remedied as Alpha matured. Slight physical effort may produce similar symptoms in sedentary men, while hard labor may leave trained athletes unaffected. The post-feeding P/R ratio in each month was not significantly different from the respective pre-feeding P/R, again asserting the relative constancy of P/R in different physiological states.

Other activities. Thumb sucking appeared as early as the second day and was indulged in frequently in the first month, and although the habit persisted throughout the year, it became relatively infrequent after the second month. During thumb sucking both pulse and respiratory rates were accelerated slightly above normal with greater acceleration in respiration than in pulse. Kicking the four limbs in the air was observed most frequently while she was lying on her back in the crib during the early months. This activity was extremely variable and hence elicited various physiological responses. It occurred spontaneously or when any part of her body was stimulated. In the first month kicking did not greatly affect respiration but accelerated the pulse, in the fourth month both pulse and respiration were accelerated, and in the fifth month pulse remained about normal while respiration was accelerated. Trying-to-walk activity appeared first in the third month, and was characterized physiologically by increased pulse and nearly normal respiration. Rolling-over was noted first in the third month when apparently in a rage Alpha rolled about over the floor. In this activity both pulse and respiration were accelerated far above normal. Walking appeared in the fourth month, at times resembling more a run than a walk. Upon reaching a fair stage of proficiency in walking Alpha could cover a distance of one-third meter per second, and later one-half per second. Usually she would run two to three meters at a stretch and then pause before going farther. For our measurements she was led by hand and was kept walking for ten minutes; that is, the activity was forced

on her. Both pulse and respiration were accelerated in walking, and in the seventh month, when she was led about more briskly, the accelerations were greater, while in the eighth month the two rates came nearer to their respective normals, although she was exercised to a greater extent. The acceleration is shown graphically by the points marked by a black circle in figures 4a and 4b. As in the case of feeding activity, pulse and respiration tended to remain nearer normal when she became more adapted physiologically to walking. Walking erectly was first noted in the sixth month. In this activity pulse decreased slightly below normal while respiration rose above normal. She began to climb wiremesh cage walls in the seventh month. In this activity both pulse and respiration were accelerated. She also climbed the attendant's body, and both pulse and respiration were accelerated in the exercise, but not so markedly as in climbing cage walls. In the eighth month the climbing activity accelerated the rates less than before. Here again her physiological adaptation became evident. It has been shown that pulse and respiration were accelerated to various degrees in activity but that P/R ratio for each activity as compared with the normal P/R for a particular month remained relatively constant. In only a very few cases did P/R in activity differ significantly from normal P/R.

Therefore it may be said that both pulse and respiratory rates were accelerated in activity and that one was accelerated relatively more or less than the other depending upon the type of activity engaged in; that such acceleration disappeared in the course of physiological adaptation to a particular type of activity; and that the ratio of pulse rate to respiratory rate in activity remained nearly as constant as the ratio under quiet conditions, indicating an equally efficient coördination between pulse and respiration.

Other incidental observations. During the course of the year Alpha experienced one major illness. In the tenth month she suffered from summer diarrhea characterized by liquid or soft stools, loss of appetite, and retardation in growth. Introduction of new kinds of food perhaps precipitated or aggravated the symptoms. During the winter months she suffered occasionally

from mild rhinopharyngitis characterized by sneezing, coughing, seromucous and mucopurulent nasal discharges, and high temperatures. Urine was usually neutral, although slightly alkaline at times. In the early months urination occurred as often as fifteen or more times in twenty-four hours, but in the later months the frequency was reduced to about half. Normal feces were typical of cow-milk diet, light vellow in color, neutral or slightly alkaline in reaction, and firm and homogenous in consistency. Defecation in the early months occurred about six to eight times in twenty-four hours, but in the later months the frequency was reduced to about four. Blood in the fifth month still showed infantile characteristics. It was markedly achromatic and ansicytotic. The cell counts were: red, 5,744,000; white, 9,550; hemoglobin, 72 per cent; color index, 0.7. The differential counts were: neutrophiles, 40 per cent: lymphocytes, 54 per cent; mononuclear cells, 2 per cent; eosinophiles, 4 per cent.

General summary. Summarizing, it may be said that (1) diffused and generalized body responses were gradually replaced by more localized and specific responses; (2) temperature regulation became more efficient so that temperature remained constant in varying external conditions and under various physiological conditions; (3) normal pulse and respiratory functions decreased gradually in rate and increased in stability; and further, were decelerated in sleep and accelerated in activity; (4) pulse and respiratory rates became more distinct between waking and sleeping states, as daily activities increased in kind and amount, but less distinct between normal and active states, as physiological adaptation to particular types of activity was consumated; (5) the coördination between pulse and respiration was very early perfected so that the ratio between the two rates remained nearly constant under various physiological conditions from month to month. Therefore it may be said that the physiological maturation in our subject consisted in an attainment of stable and adequate coördinations among different physiological systems so that the organism could maintain its functional efficiency unimpaired under varying and various internal and external conditions.

IV

BEHAVIORAL DEVELOPMENT

Introduction

The behavioral development of the chimpanzee infant from birth through her first year presents a great diversity of observations. These data could be presented according to several plans; namely, as a diary account; as cross sections of behavior at stated intervals; or as developmental sequences and patterns of behavior. The third of these alternatives has been chosen as the chief mode of presentation since it gives the greatest coherence to the behavioral account itself, and also lends itself most adequately for comparisons with the development of other primates.

The classifications of behavior used in this report are not to be regarded as being necessarily discrete categories nor as being inclusive of the entire range of the infant chimpanzee's behavioral repertoire. Rather they are overlapping accounts of the organism's development as viewed from certain arbitrary but useful points of emphasis.

A word of caution against too free interpretation is also in place. The environment of the animal whose growth is here reported deviates tremendously from that of the wild chimpanzee. We do not know to what extent the diet offered is inferior or superior to that of the chimpanzee in the bush; stimulations and inhibitions from creatures of its kind have largely been lacking during the first year; and on the other hand, opportunities and necessities for certain adjustments have been thrust upon the organism by the laboratory situation. Such considerations as these point to the need for extreme caution in interpreting the results of our observations. Indeed, it is questionable whether or not this animal is characteristic of laboratory chimpanzees. The opportunity has become available to observe the behavioral and physical growth of several chimpanzee infants which had been subjected to varied environmental influences before being brought to the Yale Laboratories. While these observations do not show any major deviations from the picture here presented. they nevertheless emphasize the importance of considering individual differences. No effort has been made in this report to compare Alpha with the other four chimpanzee infants in the Yale Laboratories, since complete life histories of a detailed nature are not available.

In order to give a certain orientation to the total developmental picture, the second mode of presentation, cross sections at stated intervals, has been employed as an introduction to the detailed consideration of the various behavioral sequences and patterns.

Cross-sectional summary of behavior

First month. The chimpanzee infant was a highly dependent organism, whose locomotor behavior was largely restricted to postural adjustments, clinging to suitable objects, or lying in either prone or supine positions. The greater part of the time was spent in sleep, which was interrupted by brief periods of activity at feeding time. The infant adapted readily to nursing and was eager for food even to the extent of sucking its thumb before meals. Fear and probably rage constituted the emotional repertoire at this time. Toward the end of the month early postural adjustments for creeping occurred.

Second month. The second month was characterized by progressive postural and early locomotor developments, beginning of simple play, and grasping which was occasionally followed by oral examination of the object. Vocalization continued to be restricted to the high pitched fear scream. Emotional expression included fear and rage.

Third month. Alpha made great advances toward independence. Definite forward progression by crawling, assumption of an upright sitting position, then standing on all fours and the first walking, successively developed. Play, exploration, and manipulation extensively increased in frequency and complexity. Soft barking was added to the vocal repertoire. In general the month saw a change from a very dependent organism to a "going" organism, capable of responding adaptively to a wide range of environmental situations.

Fourth month. There was a gradual expansion and regularization of the tremendous advances of the preceding month. Walk-

ing, grasping, and manipulation were accomplished with greater skill. The infant showed much interest in human faces and made unmistakable social responses to human beings.

Fifth month. Alpha explored and manipulated many objects about the house, played with an article for a short time, then went to something else. Climbing and jumping were new developments in motor sequence. Play threatening and attacking were observed, as well as emotional responses which are best described as mild excitement. The infant regularly assisted with her feeding.

Sixth month. Play was varied and complex. Much of the earlier passive exploration gave way to aggressive manipulation. Threatening and swaggering were seen frequently, as well as the more recently developed timidity or mild fear. Extensive climbing and occasionally standing erectly were noted. Walking erectly followed standing erectly.

Seventh through ninth months. The infant now reacted to several objects at a time, and frequently collected a miscellaneous assortment, sometimes using them for decoration of her body. There was a marked increase in timidity toward strange objects and people, in contrast to the lack of fear in similar situations during the earlier months. There was indication that the rate of behavioral development tended to diminish during this period.

Tenth through twelfth months. Alpha was introduced to an infant chimpanzee, Bula, slightly older but less well developed physically. Aggressive attack characterized Alpha's behavior during the first four weeks they were together. It was gradually replaced by toleration on Alpha's part and later by acceptance and mutual dependence. Individual exploration and play continued as before in addition to the development of extensive social behavior between the two infants.

In summary, we note that the chimpanzee infant developed from a dependent organism to an individual capable of a considerable degree of independence; that she acquired skill in the control of her body; that her play progressively passed from the simple to the fairly complex; that a variety of emotional responses characterized her behavior; and that social adjustments to her kind and to human beings were made. Although these cross sections give only a brief outline of the infant's behavior, it is hoped that they have supplied a certain general orientation preparatory to the consideration of patterns and sequences of behavior.

The motor sequence

The influence of the laboratory situation on the behavioral development is noticed in the first observations regarding the posture of the infant. If the animal were being cared for by the mother, its most frequent posture for the early period of life would be clinging to the hair of the mother's abdomen and chest in a ventro-ventral position, partially supported and maintained by the mother although to a very considerable degree dependent upon its own grasping and clinging abilities. In contrast to this, the baby was placed in a supine position on a soft pad in its sleeping box. During waking periods thrashing and kicking about formed a large part of its activity. When by its efforts the hand chanced to come in contact with an object, attempts were made to seize, grasp, and cling. There was not at this time, however, directed reaching and grasping.

The major portion of the time was spent in a supine position, the legs were drawn up to the body, toes frequently clenched, while the arms were across the chest, at the side or overhead, usually flexed at the elbows, fists tightly closed. When put in the prone position the distribution of the limbs changed but little. Only rarely, and then during periods of activity, was complete extension of the limbs approached. At this early stage the head was held erectly without support when the infant was in an upright posture. The eyes followed a bright moving object. First and second weeks. The first efforts at forward progression were noted when the infant was placed on its stomach. The hands remained passively at the sides, the feet made alternate stepping movements, and the head and neck were extended and raised from the floor. Third week. Later the arms were regularly extended in advance of the body, enabling the animal to raise the head and chest from the floor. The head and chest were also raised when the infant was approached with the nursing bottle or when it was taken up from the bed. Turning of the head in addition to eye movements was noted when the animal observed moving objects (people, nursing bottle, dog, etc.). Fifth week.

The succeeding weeks produced rapid changes in behavior. The arms now began to play an active part in crawling, although they were poorly coördinated with the legs. The head was held higher and moved from side to side in unison with the stepping movements. Greater facility in the manipulation of the limbs was increasingly evident, even to the extent of sucking toes. Seventh week. The legs were progressively extended further, and there was less kicking and thrashing. Toes were brought to the mouth frequently, hands grasped the feet skillfully, and occasionally foot grasped foot. The head and neck were raised easily and the position maintained for longer periods. Eighth week. The animal raised herself from a supine to a semi-erect posture by pulling on several pieces of cloth which had been suspended above her head. This position could be maintained for a few minutes but only with support. Ninth week. Alpha was held by one hand and lowered toward the floor. As her feet touched the surface, knees slightly bent, she rested her free hand on the floor in chimpanzee fashion, fingers flexed so as to throw the weight on the knuckles rather than on the palm of the hand. This bit of behavior takes on increasing significance when we consider that it is part of the typical motor pattern of the adult chimpanzee, appearing in this infant without opportunity for tuition, and presents a striking deviation from the motor sequence of the human child. In the crib she turned from back to side by grasping the foot with the hand of the same side, flexing the back, and kicking with the free hand and foot until the change in position was effected. Within two days this response had been extended to include turning from back to stomach, and was a frequently repeated activity. Tenth week.

Crawling changed markedly; the arms, now coördinated with stepping movements of the legs, remained in advance of the body but were drawn closer to the chest and frequently supported the weight on the elbows. This tended to exaggerate the swaying movements of the head and shoulders previously noted. The first approach to the assumption of an upright posture was observed when the animal raised its head and shoulders high above the floor of the crib, resting the weight of the body on the hands with the arms fully extended. This probably represented a preliminary step to the gaining of the sitting posture from the prone position, although the arms at this time were still extended too far in advance of the body for sitting. The animal now turned freely from back to stomach and stomach to back. No complete roll, stomach to back to stomach, was observed until much later, in the course of play responses. Eleventh week.

The animal now regularly assumed an erect sitting position. The arms were fully extended and adducted closely to the body, while the feet were drawn up underneath, in contrast to the earlier extension behind the body. This sitting position was at first maintained for only a few seconds before the animal fell to either a supine or prone position, only to repeat the activity in a short time. In the early efforts both arms were used to support the body, although by the end of this week she frequently supported herself on one arm, while exploring the crib with the other. It is significant to note that the typical flexion of the fingers and throwing of the weight on the knuckles were observed with great regularity. On several occasions the animal rose on all fours, maintained this position for a few seconds, and then fell flat to the floor. No attempts at progression were observed. Twelfth week.

The animal sat erectly frequently and for long periods of time, usually resting one hand on the floor for support. From this position she arose and stood on all fours and early in the week was seen to take one step forward. Within twenty-four hours of this observation the infant was making repeated attempts to walk, and by the end of the week, slowly, with effort and some failures, had traversed the length of the cage (three feet). Vocalization, a soft bark, indicative of excitement in older animals, frequently accompanied these early efforts at walking. Thirteenth week.

Skill in walking on all fours came with rapidity and the animal

fell less frequently. Small objects in her path were avoided. From either the sitting posture or while walking Alpha occasionally stood upright, placing her hands on convenient objects for support. Incipient climbing responses appeared when the animal, supporting herself by her hands on the edge of the box, thrust one foot over the edge, although she continued to rest part of her weight on the other foot which remained in contact with the floor. This behavior was repeatedly observed on subsequent occasions, but it was not until two months later that climbing actually appeared as a component of the behavioral repertoire. It perhaps would not be out of place at this time to emphasize the fact that when a certain bit of behavior was once accomplished, e.g., sitting erectly, walking on all fours, walking erectly with the support of objects, that particular activity was extensively indulged in until it in turn was displaced by a later development. Fifteenth week.

Standing erectly with support was now extended to include walking erectly with support. Seventeenth week. The animal now walked on all fours for long distances (20 to 50 feet), sometimes interrupting the forward progression by sitting down, then going on, until the desired objective had been reached. A frequent termination to such excursions at this time was sprawling with the limbs extended near the object toward which she had been walking and making short subsequent explorations in this position. In the restricted region of the crib, walking erectly with support was common. The increasing facility in the use of the members of the body was indicated in the assumption of an erect standing posture from a sitting position without using the hands, although support was necessary to maintain this position. Twentieth week.

The ascent of two steps was accomplished with great effort. Approaching the stairs on all fours, Alpha placed her elbows on the first step, then gradually advanced the upper body, and squirmed and wriggled until the feet had been worked onto the step. In attempting the third, the effort apparently was too great, she whimpered, later screamed in a temper tantrum, kicked, finally rolled down the two steps so laboriously ascended.

and screamed until diverted to another activity. Twenty-first week. The first observation of jumping, in which both feet were raised simultaneously from the floor and the weight supported on the hands, was made during this week. Twenty-second week. The animal now ran on all fours from one place to another. Twenty-third week.

Skillful climbing appeared rather suddenly. The animal climbed the side of the cage, inserting her fingers in the wire-mesh top of the crib and raising herself until the feet rested on the edge of the box portion of the crib. Within a few days she climbed by bracing herself against the projecting edges of the cage as well as by the method described above. No attempts to climb out of the cage had thus far been made, although there had been ample opportunity. The first observed attempt to walk erectly without support occurred as the animal was crossing a room on all fours. When about half way to the objective she gradually raised her shoulders until the hands were swinging freely about 4 inches from the floor, took one step forward in this position, and then continued advancing on all fours. While there was much swaying in the erect position, there was no break in the forward progression. Twenty-fifth week.

Climbing became a very prominent bit of behavior. Alpha now climbed out of her crib, on and about the rungs of the chairs, into persons' laps, and hung for short periods from the edges of tables and other furniture. Descending from an object she rarely fell but gradually lowered herself until the feet came in contact with the floor, or hung and definitely dropped to the floor. In climbing activities the arms were the dominant members. Twenty-eighth week.

Walking erectly without support for relatively short distances, three or four steps, frequently occurred as the animal approached a person or object and constituted the last part of the locomotor activity needed to reach the goal. Twenty-ninth week.

Jumping, either on her hind feet or on all fours, was now often seen and apparently was being incorporated as part of the play activity, since it was repeated many times within a short period. Jumping from an elevation toward an object was noted.

Alpha now climbed over almost any obstacle in her path with ease and alacrity. She chinned herself on the edge of the table, then hung on by one hand while exploring the table top with the other. Climbing had definitely been established as a mode of locomotion. Thirty-third week.

The animal walked erectly on many occasions and had gained sufficient skill to descend two steps while upright and to carry an object in each hand for a considerable distance. Thirty-ninth and forty-fourth weeks respectively.

Further developments in the motor sequence were adaptations of the above behavior to meet particular needs and were not an essential part of the motor development; hence they will be considered in relation to their associated activities, play and social responses.

Comparison with captive chimpanzee infants. It is proper to inquire how representative Alpha is of chimpanzees in captivity and to what extent the laboratory situation may have introduced artifacts and changes in her development. Three sources of information have been consulted, none of which presents detailed or complete accounts, von Allesch (1921), Yerkes (1925), Yerkes and Yerkes (1929) and White (1929).

Possible variations introduced by laboratory care of the infant include the following:

- 1. The clinging response of early infancy was not exercised. The observations of von Allesch and Yerkes indicate that the infant under the care of its mother spends a great part of the first two months clinging to the mother's skin and hair. Obviously Alpha did not have such opportunity. Except for its possible significance in climbing, this lack apparently has not seriously influenced subsequent development.
- 2. The prone and supine positions were over-emphasized. This condition existed especially during the first six to eight weeks and to a much lesser extent thereafter. The report of von Allesch indicates that the mother on numerous instances places the infant in a reclining position in the groin of her body. Also when the mother reclines the infant finds itself in a prone position. It would seem then that the laboratory situation has emphasized

a condition present under more natural surroundings but has not introduced an essentially strange factor.

A phase in the motor sequence in which the influence of such emphasis might be expected to show itself is in the crawling activities, especially in the coördinations between arms and legs. Von Allesch observed that the legs made pushing movements while the arms clung to the mother's body as the infant struggled to reach the nipple. Alpha's early attempts to crawl exhibited the same essential features of integration.

- 3. Climbing may be delayed. Specific mention of climbing behavior in the young infant has not been made by these writers, apparently for the obvious reason that this is probably an activity indulged in by the infant a great part of the time, and hence does not appear as a discrete bit of behavior at some subsequent period. In Alpha's case opportunities for climbing were less adequate than under natural conditions, and the development of this behavior has probably been retarded.
- 4. Walking may be accelerated. Certainly walking does not appear to have been retarded, and may even have been accelerated. Yerkes has reported that the chimpanzee infant usually walks before six months. In the observations of von Allesch and of Yerkes the mother's tutorial guidance has been described as early as the third month, although independent walking has not been reported at this time.

White has reported a series of incidental observations on the development of an infant chimpanzee born in the Philadelphia Zoological Garden. Unfortunately these observations are not recorded in sufficient detail to permit close comparison with Alpha's development, and the death of the infant at six months precluded further comparison in the latter half of the year. The following statement constitutes an approximate evaluation of the development of the two chimpanzees.

- (1) Alpha appeared to be accelerated from two to three months in physical growth, as judged by increases in weight and stage of dentition.
- (2) Alpha was at least three months ahead in motor development, since at the time of death the Philadelphia infant was

unable to walk on all fours or to sit erectly. White has interpreted the delay in motor development as a function of the lack of mother's care and tutelage. Our observations do not support this suggestion.

(3) Vocalization, emotional and social responses showed many common characteristics.

From the information available from these three sources it seems evident that the behavioral and physical development of Alpha has not been retarded, and in some respects was distinctly accelerated in comparison with other captive chimpanzee infants.

Comparison with the human infant. The comparison of Alpha and the human infant with respect to the rate and pattern of development yields highly significant information. Such a comparison is made possible through the work of Shirley (1931), from whose study of twenty-five infants during the first two years the following quotation is made (pp. 194–195). The numbers in parentheses following certain items indicate the age in weeks when the behavior appeared in the human and in the chimpanzee infants, and are not part of the quotation (human/chimpanzee).

Specific phases of motor development

- 1. Progress toward creeping goes through the following stages:
 - a. Lifting the head, chin free, when on the stomach; (3/3)
 - b. Lifting the head, chest free, when on the stomach; (9/5)
 - c. Knee pushing or swimming; (25/7)
 - d. Rolling; (29/8-10)
 - e. Rocking, pivoting, worming along; some method of making progress; (37/11)
 - f. Scooting backward by using the hands;
 - g. Creeping forward.
- 2. Progress toward assuming an upright posture goes through the following stages:
 - a. Lifting the head when lying on the back; (15/5)
 - b. Sitting alone momentarily; (25/12)
 - c. Sitting alone; (31/13)
 - d. Standing, holding to furniture; (42/15)
 - e. Pulling self to standing position by means of furniture; (47/15)
 - f. Sitting from standing position.

- 3. Progress toward walking goes through the following stages:
 - a. An early period of stepping;
 - b. Standing with support of a person;
 - c. Walking with help, led by a person; (45/17)
 - d. Standing alone; (62/20)
 - e. Walking alone; (64/25-29)

A comparisom of sequential motor development in the human infant and in the chimpanzee presents in general striking similarities and a few significant deviations. Disregarding for the moment the accelerated growth of the chimpanzee, and considering only the sequential pattern, we note that in making progress toward creeping the chimpanzee infant passed through the first five stages. Thus, Alpha successively lifted the head, chin free; lifted the head, chest free, when on the stomach; attempted to make forward progression by pushing with the legs; rolled when on her back; and pivoted and wormed her way forward. thus far there has been item for item correspondence, the next phase, scooting backward by pushing with the hands, did not appear in this chimpanzee. At this point in the development the preliminary phases to the assumption of an erect sitting position appeared, and instead of movement backward, pushing with the hands resulted in the assumption of an upright sitting posture (see eleventh and twelfth weeks). Creeping forward, the last phase, likewise was absent; in contrast Alpha stood and walked on all fours.

Similar correspondence is noted in the assumption of an upright posture. With the exception of the last item, i.e., sitting from a standing position, the various phases of the sequence were successively exhibited. However, in the case of the human infant, with respect to items b and c, sitting alone in an upright position, it should be noted that the human is placed in this position and simply maintains it, whereas the chimpanzee assumes this posture by its own efforts. Attempts to place Alpha in a sitting position, previous to her own assumption of this posture, had met with failure.

While walking erectly is a less frequently used mode of locomotion in the chimpanzee, its development nevertheless follows

that of the human infant. Adequate tests for early stepping movements were not made and incidental observations furnish no clear-cut information. With respect to the second item, standing with the support of a person, it should be noted that when Alpha first stood on all fours she very soon pulled herself to an erect standing position by means of furniture or the crib. Before this time it had been impossible to place her in an erect standing posture under the conditions used in the human infant study. In the case of item c, walking with help, led by a person, an approximation of behavior is substituted; namely, walking erectly while supporting herself by resting one hand on a piece of furniture. Standing alone and walking alone followed in their regular order.

Two distinctly chimpanzee features of the locomotor sequence should be mentioned: skillful climbing and extensive jumping in a variety of conditions. While these activities unquestionably have their counterpart in later human development, they do not at this period lend themselves to comparison.

Relation between behavioral and skeletal development. While the sequence of events in the development of locomotion in the chimpanzee and human infants show a striking parallel, the temporal relations present a marked contrast, in that the various developmental phases appeared in the chimpanzee from two to three times earlier than in the human infant. In the preceding chapters the physical growth and physiological development have been outlined. It now becomes of vital interest to compare the accelerated development of the motor sequence in the chimpanzee and a logically related measure of physical maturation, namely, skeletal age as determined by the appearance of ossification centers. These data are presented graphically in figure 5.

Chronological age is represented on the abscissa, behavioral and skeletal ages on the ordinate scale. Since both behavioral and skeletal ages are expressed in terms of human standards, the curves for these functions in the human infant necessarily coincide by definition and present a point for point correspondence with chronological age (solid, heavy, uninterrupted line on graph).

The key for the various aspects of skeletal and behavioral development in Alpha is given in the graph. Inspection of figure

5 shows (1) that in creeping, sitting, and walking the chimpanzee infant is increasingly accelerated over healthy human infants;

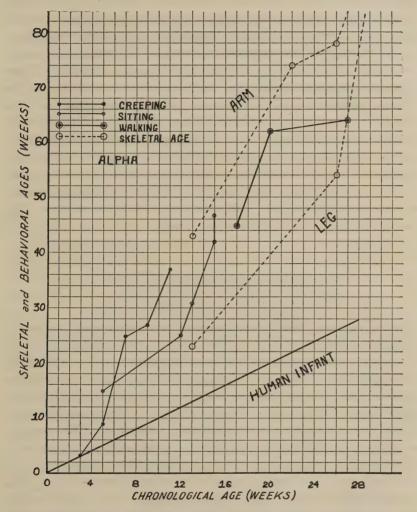


FIG. 5. RELATION BETWEEN SKELETAL AND BEHAVIORAL AGES

(2) that the chimpanzee is also accelerated in skeletal development, the arms more so than the legs; and (3) that the extent of the behavioral acceleration approximates closely that of the

skeletal. It is unfortunate that skeletal ages are not available before three months. This deficiency has been remedied to some degree through the kindness of Professor Todd who has made available the observations of himself and his co-workers on two chimpanzee fetuses. Their findings indicate that the fetal chimpanzee during the later stages of growth is not greatly advanced over the human fetus in skeletal development, and hence lends support to the assumption that Alpha's skeletal development was not far beyond that of the human infant during the first few months of her life. If such an assumption is verified in later studies on living chimpanzees, the writers feel that the observations on the behavioral and skeletal growth of Alpha offer further evidence of the close relationship between these two developing systems. The close correspondence of the motor sequence stands in sharp contrast to the low correlation between skeletal age and the more complex adaptive responses.

v

BEHAVIORAL DEVELOPMENT (CONT'D)

Reaching, grasping, and manipulation

Reference has already been made in the discussion of the motor sequence to the early efforts of the infant to grasp and hold tightly any objects which chanced to come in contact with the hands. The significance of this early grasping seems to lie in its relationship to the maintenance of contact with the mother's body. Alpha's grasp from birth on was at all times very strong and capable of being continued for considerable periods. This was not reaching and grasping of a directed nature, such as is seen at a later date, but was rather a reflex grasping followed by flexion of the arms so as to bring the infant's body into closer relation with the prehended object. The ability to hang by one hand has remained a part of the animal's behavioral repertoire and never was there indication of a diminution of its strength such as is seen in the development of the human infant, in which case this behavior tends to disappear with the development of the eve-hand coördination.

Incidental observations. In contrast to reflex grasping, the development during the first week of the hand to mouth reaction, sucking fingers or fist, is noteworthy because of its relation to acquired reaching and grasping responses. First week. The first definite observations of reaching, although there was no subsequent grasping, were made when Alpha raised her head and extended her arms upward when she was approached with the nursing bottle. Fifth week. Hand play, especially opening and closing the fist, had started to a slight extent. Thumb sucking continued and toe sucking made its appearance. Seventh week. Reaching and grasping of toes and hands with good coördination developed subsequently. When she grasped with her hand the thumb was sometimes used, apparently more or less by accident, and never in effective thumb-fingertip opposition. However, the squeeze grasp with the thumb in line with the fingers was the technique most frequently used. Eighth week.

An obvious change took place in the animal's behavior in that what may be called directed grasping was frequently observed. Small objects, such as bits of paper on the floor of the crib and pieces of cloth stretched across the top of the cage, were definitely reached for, grasped, and occasionally carried to her mouth. It is interesting to note that at this time she did not reach for and seize proffered objects, pencils, blocks, wooden ring, etc. In the yard she stretched her neck in order to get blades of grass into her mouth. This use of the mouth in reaching for objects may have been to some extent the result of her inability to use her arms which supported the weight of the body when she was in a prone position. Other observations indicate however that the above factor was not entirely responsible for this behavior, since it appeared in situations in which the arms were free to be used in reaching, and continued beyond the first year as one of the most frequent means of examination and manipulation. Coincidentally with the development of grasping, Alpha learned to turn from back to stomach. In this activity grasping foot with hand played an essential part. Ninth through eleventh weeks.

Rapid advancement in reaching and grasping was shown in a variety of ways during the next few weeks. When brought close

to a person's face she looked at it carefully while examining it with lips and fingers. Projecting surfaces of the crib, such as the warm air grille, nuts and bolts, or small objects in the crib. were examined repeatedly. In these activities, although the lips, tongue, and teeth were most frequently used, the fingers, particularly the index finger, took an increasingly important part. foot was occasionally used in grasping with as much skill as the hand. In light of the later manipulation of small objects with the two index fingers, the early use of the forefinger in tracing the grain of the wood or the outline of objects is noteworthy. Definite manipulation was seen when Alpha tore paper from the floor of the crib and carried it to her mouth. Correlated with the increasing use of the hands in exploration was the assumption of an upright sitting posture, standing on all fours, and early efforts Thirteenth week. to walk.

While sitting erectly Alpha tried to reach a suspended spool with her mouth, but failed, then hit at it with her hand, finally grasped it and immediately brought it to her mouth. After this she was seen to grasp the rattle with her foot and take it to her mouth by guiding her foot with her hand. At various times she helped to hold her bottle and to guide the spoon to her mouth; tried to remove our eye glasses; scratched the wall continuously; and manipulated the loose canvas cover of the cage. The hands were now definitely preferred to the mouth, and although grasping was by no means precise and accurate, nevertheless, reaching, grasping and manipulation became a large and important part in Alpha's daily behavior. Fourteenth through sixteenth weeks.

Further development of skill in grasping in everyday situations was evident from such behavior as guiding the spoon to her mouth, twenty-first week; picking up electric light cords and pulls with her fingers, twenty-third week; picking up the nursing bottle from the floor by encircling it with her arm, twenty-fifth week; removing the lid from a small can, twenty-eighth week; holding a nursing bottle in each hand, thirtieth week; and carrying two objects while walking erectly, forty-fourth week. Other aspects of manipulatory behavior are considered in relation to play and social behavior.

Responses to Gesell test items. Considering the important rôle that prehension and manipulation play in human behavior it seemed desirable to collect data which would permit more or less precise comparison of the development of this behavior in the ape and in man. To this end items of the Gesell test were employed under conditions approximating the human testing situation. In the routine of these examinations the infant was held on Mrs. Jacobsen's lap, facing a card table, and at such a height and distance that the animal was free to use her hands, arms, and head in the manipulation of the proffered objects. Opportunity was given to respond to all of the Gesell testing materials, and these results are summarized in Appendix A. Responses to the cube, cup, spoon, bell, and pellet are here presented in greater detail in relation to the topic under discussion.

The first attempts to examine the infant in the testing situation outlined above failed to elicit overt responses to any of the objects successively placed before her, although in the familiar environment of the crib she had been reaching, grasping, and manipulating a variety of articles. Fifteenth through seventeenth weeks. Interest in and exploration of the table edge constituted Alpha's first positive reaction, but there were not at this time any efforts to prehend the test materials. Eighteenth week. The next response was to reach for and feel the edge of the bell and spoon with her lips, with no attempt to use her hands. Nineteenth week. As before, the cube, spoon, cup, bell, and pellet were successively placed on the table, and in each instance she attempted to reach the object with her mouth, but when restrained, corralled each with a finger or hand, bringing the arm to the object in a circuitous movement. Twentieth week. She continued, on the next observation, to corral and move the objects with intermittent and unsuccessful efforts to seize and lift them. Definite preferential interest was shown in the cup and spoon, objects associated with food in her everyday experience. Twenty-second week.

On the next test both grasping and corralling were observed. Medium-sized objects, cube and spoon, were grasped, lifted from the table, and carried to the mouth. In this process the squeeze grasp was used, and the thumb, playing no essential part, was

flexed and rested against the back portion of the palm in such a manner that the objects were sometimes held between the fingers and the dorsal surface of the thumb; at other times between the fingers and the palm. The cup and bell, relatively large, and the pellet, very small, were apparently not adapted to the infant's grasp at this time, hence were corralled and eventually brushed off the table. The grasped cube was brought to her mouth, and held there, either by her hand or teeth, until she became interested in something else, when it was dropped. Twenty-third week.

Thumb opposition to the fingers was seen when Alpha grasped the handle of the bell, and although this response occurred occasionally it by no means represented her usual mode of grasping. It is interesting to note that whether the thumb was to be used oppositionally or whether it was to function as an additional finger seemed to be partially determined by the character of the object grasped. The cube and spoon which projected but slightly above the surface of the table were picked up with a squeeze grasp, whereas the bell with its handle extending several inches above the table, might or might not be grasped with the thumb opposing the action of the fingers. In this latter instance the approach to the object and the position of the thumb appeared to be further determining factors. A sweeping approach predisposed the thumb to be a finger, whereas direct reaching was more favorable to the appearance of oppositional grasping. Similarly if the thumb were extended and abducted there was greater likelihood of opposition, while if flexed and adducted as the hand approached the object, the thumb was almost invariably used as a finger. In no case, however, was there thumb-fingertip opposition such as is seen in the later development of the human infant. Twenty-fourth week. Subsequent observations indicate that at least for the first year, and possibly longer, thumb opposition was often accidental and of little significance in grasping large and medium-sized objects. However, it appeared to be of greater value in picking up small objects such as the pellet. (See thirtieth week of this sequence.)

The small sugar pellet still presented difficulties, but now Alpha moved it carefully toward her with the index finger. Her first

simultaneous manipulation of two cubes was to move one to another with her hand, then lower the head, and try to mouth both at once. On this same day she gave further evidence of being able to handle two objects simultaneously by holding a cube in her mouth while handling the cup. One of the incidental uses of the thumb occurred when she picked up the spoon between her index finger and the knuckle of her thumb. Twenty-sixth week. Success in grasping the cup finally came when she encircled it with her cupped hand and brought it to her mouth. There was no response to the handle. Twenty-seventh week.

A new development in her efforts to pick up the pellet was the simultaneous manipulation with the index fingers. In doing this. she repeatedly moved the pellet off the table but failed to grasp or to lift it. It is interesting to note the early appearance of this manipulatory response which is so frequently seen in the fine motor adjustments of the older chimpanzees, especially in skin dressing. (See p. 75 for the appearance of this behavior in Alpha.) Up to this time Alpha had failed to accept a second cube while holding the first, whether it was presented on the table or put to her hand. Now she grasped one cube, held it to her mouth, and finally grasped a second; then dropped the first after five seconds to finger the second. She refused a third cube. ninth week. The infant finally succeeded in picking up the pellet by pinching it between the forefinger and flexed second finger of the same hand. On other occasions she seized the pellet and other small objects between the thumb and ulnar side of the first finger. On this same day, she picked up one cube in each hand, then dropped one in order to finger the third. Upon repetition, she grasped a cube in each hand while accepting a third with her mouth. Thirtieth week.

An indication of some breaking down of the hand-mouth reaction was evidenced when Alpha took one cube in her mouth, grasped a second, then threw it down and played with it on the table. This was the first time that she definitely threw down the cube, or played with it other than to mouth it. Thirty-third week. Later she took successively two cubes in one hand, and picked up a third in the other hand. Thirty-seventh week. When four

cubes were exposed on the table at once, she corralled them with a sweeping motion of the arm and grasped two of them. Fortieth week. Subsequent to the thirty-fifth week a definite loss of interest in playing with the cubes was noticed.

In summarizing the reaching, grasping, and manipulatory behavior of this infant chimpanzee, and comparing it with that of the human infant (Halverson, 1931), certain likenesses and deviations should be noted. The early features of the two patterns are quite similar in that there was regard for objects without efforts to reach, followed by reaching and manipulation without grasping, and finally by grasping. While the general sequence of this early development has been similar, marked deviations from the human pattern have appeared. The mouth, which was persistently used in early attempts to reach and grasp objects, continued to play a much greater part throughout the first year of the chimpanzee's life than it does in the human infant. While marked similarity in the squeeze type of grasp has been noted in the chimpanzee and human infant, there is a definite failure in the chimpanzee to develop effective thumb-fingertip opposition within the period of these observations.

The failure to develop effectively beyond the squeeze type of grasp is readily understandable when certain anatomical features of the chimpanzee hand are considered. The fingers of the chimpanzee are relatively long, whereas the distal end of the thumb does not extend beyond the distal ends of the metacarpal bones. In addition to the shortness of the thumb, its thickness and strength are markedly less than those of the fingers, and its ossification greatly retarded.

Vocalization

During the first eight weeks of life vocalization was extremely simple, being limited to a cry which resembled closely the screaming of immature chimpanzee children when frightened or angered. This cry started in a middle register and terminated crescendo in a series of short high-pitched screams, and was associated with behavior patterns which, differentiated on the basis of the situation and other features, are commonly characterized as fear. At the

end of this period incipient movements of vocalization, i.e., protrusion of the lips, were noted for the first time, although there was as yet no audible sound. *Eighth week*.

The next type of vocalization, the chimpanzee bark, a series of short, guttural "u"s, occurred in response to the authors' attempts to imitate this call. Although previously Alpha had failed to respond to this situation, she now immediately turned her head in the direction of the sound and responded by protruding her lips (see above) and answering with a soft bark. Ninth week. In the following week while at the laboratory the infant heard the older animals calling, and, although she did not see them, turned her head in the direction of the sound and responded with the soft bark. Tenth week.

Whimpering, a type of response definitely distinguishable from the soft bark, was first noticed in association with soiling or wetting the crib, and soon replaced the original kicking response under these conditions. Twelfth week. This whimpering appeared throughout the year on occasions of mild fright or timidity, and under continued stress developed into the fear cry. On other occasions, when left alone in the crib or when placed in the crib after play, Alpha whimpered but desisted if given attention or if ignored.

In contrast to whimpering in mild fear situations was the use of the soft bark under conditions of mild excitement. Thus Alpha barked continuously while walking after she had reached a certain degree of proficiency in locomotion (see motor sequence, thirteenth week); she greeted us by rising to all fours and barking when we approached the crib, thirteenth week; later, called when she saw her food, seventeenth week; and barked softly and continuously while manipulating the loose canvas over her crib, eighteenth week. A further use of the bark during mild pleasurable excitement was seen in its incorporation in threatening behavior. Twenty-second week.

The vocal play, or babbling and cooing, of the human infant, was never duplicated or, in analogous forms, even approached by this animal. Vocalization was directed toward some immediate environmental situation and appeared in anger, fear, "desire for

attention," threatening, hunger, or in response to certain noises. The nearest approximations to the vocal play of the human infant were seen in the soft barking while walking or manipulating the canvas.

A different type of vocalization was elicited when the infant examined the author's faces with her fingers. It may be characterized best as smacking, involving alternate opening and closing of the mouth without, necessarily, any expulsion of air. Seventeenth week. This response was shown much later as a modified component of the skin-dressing behavior (see p. 75). Thirty-seventh week.

An interesting development in her non-vocal response to verbal commands was noted when she stopped biting the furniture when "no, no" was spoken in a loud voice. Previously she had been slapped and removed from the object when the command was given; she now responded to the voice alone. Later she learned to inhibit the undesirable biting response entirely, and substituted for it manual examination of the object.

In summarizing the vocalization of this infant, we note that there are essentially four distinguishable types of vocal response: (1) fear and temper cry; (2) soft bark; (3) whimper; and (4) smacking. All four of these types were used as social responses as well as in situations asocial in character. The only certain responses to human vocalization were her answering soft bark to the simulated chimpanzee call, and the inhibition of biting the furniture at command. Later vocalization involved the extension of the responses already acquired to a large number of stimulating conditions and are more properly considered in their relation to social, emotional, and adaptive behavior.

In comparing the infant's vocal repertoire at the end of the first year with that of the adult chimpanzee, similarities in the fear and anger cry and in barking were evident. Whimpering, on the other hand, may have occurred more frequently than in the adult animal. For detailed descriptions of chimpanzee vocalization the careful technical observations of Yerkes and Learned (1925) are recommended; for the significance of vocalization in chimpanzee life, Yerkes (1925) and Yerkes and Yerkes (1929); for the vocalization of wild chimpanzees in the bush, Nissen (1931).

Emotional behavior

Four patterns of emotional behavior, in part differentiated by the character of the response and in part by the character of the stimulating situation, were observed during the first year. Fear and anger, at first poorly differentiated, dominated the infant's emotional behavior during the first two months. Two less intense emotional responses, mild fear or timidity, characterized by withdrawal, and mild excitement, or interest, characterized by approaching reactions, developed subsequently.

Fear responses. Fear responses could be readily elicited from birth onward in certain situations: (1) picking up the infant from the crib, a sudden light touch on various parts of the body, and sudden jarring of the crib; (2) complete removal of support when the infant was held in the arms; and (3) sudden intense noises. The response was characterized by sustained clenching of the feet and hands, drawing up of the arms and legs, and a tendency to cling to objects; by wrinkling of the face and retraction of the lips; and by a high pitched crescendo scream. First and second weeks. The intensity of this response cannot be easily over-emphasized, since at times it involved the entire musculature in a tonic spasm.

Observable modifications occurred as early as the third week when the animal commonly remained passive and quiet when properly supported in the attendant's hands. Adaptation to a particular manner of handling was noted in this behavior. Whereas the animal remained quiet with the usual attendants, attempts on the part of a person not thoroughly familiar with the details of care promptly called forth violent fear or possibly rage reactions. Third week. Gradual modification of the fear response was noted during the second and third months. The contraction of the bodily musculature was much less intense and of shorter duration. While at times the response might be very strong, more and more frequently the less intense start response characterized by momentary contraction and relaxation was observed. Second and third months.

The advent of walking and upright posture introduced two new features into the fear pattern; namely, effective withdrawal of part of the body and flight from the stimulus. The earlier tense reactions were replaced by this more coördinated behavior. Varying with the intensity of the situation, the animal might flee immediately, screaming, or might first withdraw from the object, retracting the arms and legs, wrinkle its face, scream, and then, finally, resort to flight.

One feature of the immature and adult chimpanzee fear pattern, sudden evacuation of the bowels, was notably lacking in the infant's fear response. Whereas defection is an almost invariable component of the fear pattern of the older animals, and developed later in Alpha, it was not observed during the period covered by this report.

With the development of play and active manipulation, Alpha produced situations which from time to time elicited pain and fear responses. Sudden movement of objects, new strange objects, and very intense stimulation frequently, although not always, caused fear. Alpha burned her finger on the water heater, tipped over a small table, upset the waste basket, and pulled down the oven door on her head; characteristically she retreated a short distance, sometimes screaming, fell flat on her stomach, and occasionally returned to investigate the object.

The following incident represents what is probably an extreme instance of Alpha's emotional response to a strange object. While she played on the floor, a white rubber ball about six inches in diameter was rolled gently toward her. When it touched her she screamed and retreated, and on subsequent occasions repeated this behavior, sometimes rolling over and over in her haste to get away from the ball as it approached her. When the ball chanced to lie in the animal's path, she cautiously walked sideways until she was safely passed it, avoiding it by several feet. when the ball was stationary, she reached toward but did not touch it. On the second day she examined the object with her lips and tongue while it was held, and was less frantic when the ball rolled toward her. Frequent offering of the ball to the infant resulted in her touching the object only when the observer held it. A week after the first presentation. Alpha cautiously approached the ball, touched it with lips and tongue, retreated, then rushed at it, striking it with the back of her closed hand. Definite play with

the ball from then on replaced the fear response. Twenty-seventh week.

Slight changes in familiar aspects of the animal's living quarters sometimes required several days for readjustment. Thus, when the floor of the crib had been newly varnished. Alpha screamed. struggled, and finally jumped out of the crib to the floor of the room. Later, she was given her bottle, and as she nursed was again placed in the crib. The infant remained quiet until finished with her milk, then glancing around, apparently saw the newly painted floor, screamed, and jumped out as before. Newspapers were then put on the floor of the crib, after which the infant played and slept without further disturbance. Complete adjustment was made in the course of a few days. Twenty-ninth week. similar although less intense response was seen when Alpha was introduced to the outdoor play cage. Approximately three weeks of daily experience were necessary before the infant played freely. Thirty-second week. Much later, while living in the adult quarters, the animal was frightened by the introduction of straw in sleeping box and slept on the floor. Forty-sixth week.

On several occasions when Alpha had an opportunity to play with other small creatures, timidity or aggression, rather than fear, characterized her behavior. At no time did she show fear toward a small adult house dog with which she had become familiar through daily experience. When the infant was able to walk and run easily, she was consistently aggressive in her attack on the dog. His snapping and growling in self defense did not deter Alpha in her attempts to pull his tail, hit at, and threaten him. Similarly, the chimpanzee showed only aggressive behavior in her contacts with a thirteen-month-old human child (see social behavior p. 77).

In the course of making observations on the chimpanzee's responses to a snake, Alpha's behavior was noted by Yerkes and Jacobsen. In light of the marked fear reaction among older animals, the contrasting behavior of this infant is suggestive. Previous to presenting the snake, several indifferent objects, an eightounce bottle, an electric light bulb, and a medium-sized tin can were placed on the floor beside the animal. In each instance she played with the object without evidence of timidity or inhibition.

Later a piece of soft white rubber tubing, 60 cm. long by 1.4 cm. in diameter, was dropped on the floor near her. Her response was notably different from that made to the other objects in that she approached it cautiously, retreated, and approached again. Throughout the period with this tube she tended to remain closer to Jacobsen, and to return to him more frequently than previously. Timidity and caution characterized her behavior, and no definite picture of fear, no pronounced avoidance, nor aggressive attack were noted. Her reaction was exploratory rather than playful or fearful. Another soft white rubber tube, 190 cm. long and 0.5 cm. in diameter, was presented. There was neither caution nor timidity, as in the case of the larger tube, but freedom in exploration and play. A detailed account of the infant's reaction to the snake is given in the following excerpt from our notes:

"At 4:01 a puffing adder (Heterodon contortrix, common name hog nosed snake) about 55 cm. long, and rather sluggish, was placed on floor near Alpha. Although she evidently noticed it immediately she gave it no special visual attention, but instead played about the room and especially with the electric lamp bulb which had been handed to her to amuse her between observational periods. After a few seconds she approached the snake and struck at it several times with the back of her hand as chimpanzees very commonly react to small living objects such as insects and rodents. The snake, thus disturbed, responded by puffing and hissing pronouncedly. Alpha gave no visible attention to either of these reactions, nor did she definitely avoid the snake. Instead she continued to play about the room, occasionally looking at the snake but not touching it. When the snake was pushed to within a few inches of her she did not seem startled, but nevertheless moved to the other side of the room. A minute or so later, at 4:10, she approached closely to the snake as it lay in one corner of the room and looked at it intently without touching it. As she did so the snake puffed and hissed without visibly disturbing Alpha. At 4:12 Jacobsen, holding the snake in his hand, brought it in contact with Alpha's hands and feet. She tried to avoid these contacts, but when the snake was placed about her neck she did not appear to be frightened, and although she removed it her response could not be described as fear.

"In general, Alpha's reaction to a snake may best be described as indicative of natural caution, slight timidity, and tendency to avoid the

living object in favor of attention to familiar objects about her. She did not follow and remain close to Jacobsen as pronouncedly as in case of presentation of the 1.4 cm. rubber tube."

Alpha's lack of fear of the snake in contrast to the intense response of the older animals emphasizes the importance of an undetermined factor, either maturational or experiential, in the development of this interesting snake-primate relationship which is given detailed consideration by Yerkes and Yerkes (1929).

The fear responses discussed thus far and the instances cited have been of a rather violent nature. Less intense fear or timidity, while perhaps essentially differing only in degree, showed certain characteristic deviations, and hence is considered independently.

Anger responses. The greater part of the emotional behavior during the first six weeks has been regarded as fear, possibly because anger was not present in the chimpanzee's behavior, or because of the observers' inability to differentiate it clearly from the fear response. It is entirely conceivable that some of the behavior associated with the routine handling of the animal and classified as fear might have been designated as rage by some other observer. Sherman and Sherman (1929) have demonstrated that a classification of emotional behavior in human infants as either anger or fear is largely dependent upon a knowledge of the stimulating situation, and that even with such knowledge there is by no means unanimous agreement among judges.

Instances which might have been interpreted as rage occurred early in the routine handling of the infant. Kicking, squirming, clenching of the fists and feet, and a scream which could not be differentiated from the fear cry, were noted. On other occasions the animal struggled, kicked, and screamed when physical measurements necessitating some restraint of her movements were made. This behavior was suggestive of rage, but possible fear of the shiny metallic instruments cannot be ruled out.

Definite and clear-cut rage responses were first noted in the feeding situation, when the infant vigorously rejected a nursing bottle after having finished her meal, *Twelfth week*, and later

frowned, kicked, and screamed when a small object was forced into her hand. Thirteenth week. Upon being placed in the crib after a period of play Alpha whimpered, apparently for attention, quieted when taken up momentarily, then screamed lustily when returned to the crib. Fifteenth week. When outdoors, the infant seemingly became angry if the observer walked away from her. At first there was soft barking as the animal attempted to catch up with the observer, but failing to do so, the bark changed in volume and pitch, terminating in the piercing anger-fear cry. Twenty-second week. Complete failure to make adjustment to this and similar situations resulted in the animal's falling flat on her stomach with either a continuation of the scream, or a reversion to side to side pivoting movements (see motor sequence seventh through eleventh weeks).

In the later period rage was generally seen when the animal was frustrated, either through the interruption of an activity, or through the forcing of an activity upon her. Thus, refusal to allow Alpha to climb into one's lap, or attempts to put her out of the lap, resulted in vigorous struggles, kicking, clinging, and screaming. Upon occasion, when she had been left alone in her crib throughout the afternoon, she barked persistently upon the return of the observers. Failing to get attention the infant screamed repeatedly and crawled up and down in the cage. Thirtieth week. On later occasions she became angry when a spoon with which she had been playing was taken from her, and again when a cup was taken from her. Fiftieth week. Throughout the vear the taking of physical measurements with the ensuing restraint frequently caused rage, and illustrate the effect of forcing the infant's activity. Persistent aggressiveness was an outstanding characteristic of the rage pattern.

Thumb sucking was originally observed in association with feeding, and continued to be an habitual response to a variety of situations throughout the first year. An incident highly suggestive in its development as an emotional substitute in a thwarting situation occurred when the animal was being fed. Because the infant during the preceding few days had not taken her cereals and vegetables well, but was eager for her milk, the nursing bottle

filled with water was offered on the assumption that she needed liquids and was eagerly accepted. Sucking started immediately but stopped as soon as she discovered the bottle contained water. The bottle was dropped and the thumb immediately placed in the mouth. The nursing bottle, this time filled with milk, was given, and readily taken and sucked. After a moment the bottle was taken away, and the water filled bottle substituted. Nursing again started, but stopped promptly, and was followed once more by thumb sucking. Twenty-third week.

Other instances of thumb sucking occurred when the infant had been left alone in her crib at the Station for the afternoon. Alpha called repeatedly, stopped when she heard someone approaching in the hall, then sat sucking her thumb as the person entered the room. Calling was immediately resumed when the observer left. This incident was repeated several times during the afternoon. Twenty-sixth week. During the period of adaptation to her outdoor play cage, Alpha sometimes whimpered and screamed when left alone, frequently terminating this behavior by falling flat on her stomach for prolonged intervals. Thirty-second through thirty-fourth weeks. After the ninth month when the infant was quartered exclusively at the Station and received much less attention, she often resorted to thumb sucking. This was especially marked when she was returned to the cage after feeding or play. Ninth and tenth months.

While thumb sucking has been discussed primarily in its relationship to rage, incidents have also been included which indicate that it might occur in any situation for which the animal has no adequate adjustment.

Mild fear or timidity. While mild fear, or timidity, probably differs only in degree from the previously described fear response, it does show sufficient minor deviations to merit separate consideration. The pattern of response differed from that of fear in these respects: (1) mild fear or timidity did not appear until the fourth or fifth month, when the infant showed marked disturbance if a stranger approached her crib or attempted to handle her; (2) there was whimpering rather than screaming; (3) while the animal retreated under both conditions, in timidity the retreat was less

rapid and less intense; the object was observed more or less continuously during withdrawal in contrast to the headlong flight in fear; (4) timidity was more readily overcome than fear. Its close relationship to fear is shown in the ease with which it broke over into the fear response under sustained stimulation.

The following examples illustrate the behavior in question. Alpha was sitting quietly when a stranger approached and placed her hand over the edge of the crib. Alpha drew back, watching the person constantly, then approached without touching the hand, jumped around, threatened, and played in other parts of the crib, frequently coming close to the hand but not in contact with it. After several minutes of such cautious exploration the infant finally touched the hand, mouthed it, pulled it further into the box, and played freely, pushing and pulling the stranger's hand. Twenty-third week. Mild fear was also repeatedly noted when the animal tipped over small pieces of furniture, under which conditions she retreated, whimpered, fell flat on her stomach, and subsequently sucked her thumb. If the disturbance in these instances chanced to be great, the fear responses appeared. Alpha's behavior in the outdoor play cage has already been discussed under fear, and we need only mention that the first violent fear responses gave way to timidity before freedom in play appeared.

Mild excitement. Mild excitement presents a distinctive behavior pattern which showed these characteristics: (1) approach toward or manipulation of the stimulating object or person, in contrast to withdrawal in timidity; (2) marked freedom of movement in contrast to the tension of fear and anger; and (3) usually vocalization of a distinctive type, namely, the soft bark, which later was replaced upon occasion by rapid inspiration and expiration without laryngeal sound production.

The above response was frequently seen under these typical conditions. At times when Alpha was apparently engrossed in sustained activity such as early walking, both in her cage and on the floor, *Thirteenth week*, or in manipulating various objects such as the canvas cover of the crib, *Eighteenth week*, this response was seen. Mild excitement likewise occurred when the infant greeted

people under conditions in which she apparently felt secure. However, this exuberance of response readily gave way to timidity, or even fear, if the stranger's behavior became overly aggressive. Other instances of excitement were seen in the mock threatening behavior. Twentieth week.

Mild excitement most nearly approximates the so-called love, or pleasurable emotion, exhibited in the cooing, babbling, and smiling behavior of the human child. Alpha was never observed to smile, laugh, or babble, and the nearest approach to this was the soft bark or the inspiration-expiration sound production. The fact that she was quieted when taken up, ran to us for "protection," and returned to touch us intermittently while playing, in addition to the mild excitement responses already noted, furnish the chief evidence of behavior which might be regarded as corresponding to love in the human infant.

VI

BEHAVIORAL DEVELOPMENT (CONT'D)

Play and exploration

Incidents of chimpanzee behavior occurred throughout the first year which probably, by majority consent, would be classified as play; other incidents occurred which similarly appeared to be exploration or examination of objects. However, many bits of behavior were seen which partook of the characteristics of both, and which could not be assigned to a single category. It has seemed better, therefore, to consider all these activities together. The behavior included under play and exploration falls into four groups, not mutually exclusive: (1) exploration, manipulation, and simple play; (2) organized play; (3) bodily activity as play; and (4) play and manipulation essentially social.

Exploration, manipulation, and simple play. During the first two months, play and exploratory activities were infrequent. Play with the hands, as well as the thumb and toe sucking which has been previously noted, were observed. First and second months. The animal's reactions were for the first time persistently directed toward objects outside the body when she explored

the walls and floor of the crib, either by scratching with her fingers, or by carefully feeling the contour and surface of the object with the index finger. Thirteenth week. This scratching behavior formed a large part of the infant's exploratory response, especially during the third month, after which it gradually decreased in frequency. On the other hand, the examination of objects with the index finger increased and constituted one of the infant's chief means of tactile exploration.

The objects examined in this manner were at first limited by Alpha's inability to get around freely. Thus, she was seen to trace the frame of the heat grille or cracks between boards of the crib. Whenever the opportunity was available, the infant examined human facial features, being especially interested in the nose and teeth. Thirteenth week. On other occasions, Alpha was observed to tear newspapers; to play with the canvas cover of the crib; to remove the observer's glasses; to grasp, push, and pull the attendant's arms; to examine the curtains and rugs with her fingers; to mouth and finger blades of grass and to draw her fingers across the sand; to bite on tables and chairs; to play with the rattle continuously; to pick up a grapefruit seed with her lips, drop it, and retrieve it time after time; to pull out and spill bags of vegetables and nuts, playing with them like balls. Thirteenth week through twelfth month.

This type of activity was the first play and exploratory behavior to develop. It continued as an essential and prominent part of the chimpanzee's play repertoire, and furnished a basis for the more highly organized play behavior.

Organized play. Under this grouping are included those activities in which the animal organized diverse activities in relationship to a central point, and was first noted late in the sixth month, when the animal tore the pages of a magazine, lay down and rolled over the magazine, walked away, then quickly returned, and grasping the torn pieces, placed them on her head several times. Twenty-sixth week. Further use of objects for the "ornamentation" of the body was frequently observed.

After a period of play on the floor with a magazine and loose pieces of paper, Alpha dropped the magazine, ran to her

travelling basket, climbed in, and played. Quite abruptly, she left the basket, picked up the magazine, and carried it to the basket, dropping it in and playing with it there for a brief period. She then returned to the pieces of paper, gathered and carried them to the basket, and continued to play with the assembled pieces. Thirty-seventh week. During an illness, Alpha had been closely confined to her cage and when taken out for play was very active. She climbed in and out of the observer's lap, chinned herself on the table, rolled and tumbled about the observer's feet, repeatedly climbed up on the radiator. stood erectly, and then jumped down, landing on her feet in such a way that some part of her body, head, hand, or foot, came in contact with the observer. While in this instance there was no arrangement of objects in relation to some central point, nevertheless, the infant's activities were organized and centered about the observer to an extent hitherto not seen. Forty-third week. Although Alpha collected pieces of paper, placed them in her basket, and used them for "ornamentation," at no time did she go through the procedure of nest-building, i.e., sitting on objects. rolling them, and folding them under her body in the fashion seen among older chimpanzees. Typical nest-building was observed shortly after the first year.

The instances of play cited, including the use of objects for "ornamentation," showed a degree of spatial orientation and organization which clearly set them off from the simple manipulation and exploration indicated in the preceding section. This complex play occurred not at all during the first five months, and relatively infrequently thereafter. It is significant, however, as anticipating a type of activity seen rather extensively both in the immature and in the adult chimpanzee.

Bodily activity as play. The behavior falling within this grouping most nearly represents "activity for activity's sake," and includes the often repeated but changing responses in which the movement or disposition of the body was the essential characteristic. The time of appearance of this type of play cannot be precisely stated. Certain phases of the motor sequence, grasping feet with hands, turning from back to stomach, and early walking

on all fours, were extensively indulged in for long periods after their development, and probably should be regarded as an early development of bodily play. Third month. Scratching the crib with the fingers, Thirteenth through fifteenth weeks; mock threatening and attack, which are described under social play; jumping up and down in the crib and crawling under the rungs of the chairs, Twenty-second week; were successive developments of the behavior under consideration. Sustained play of this type was observed when Alpha climbed in and out of the travelling basket time after time, fingered the hasp and handle, then returned to climbing over the edge of the basket. This play continued wthout interruption for approximately a half hour. Twenty-seventh week. Climbing over the rungs of the chairs replaced crawling under them, and the infant sometimes spent several minutes doing this, then went on to other activities. On other occasions, Alpha, in going from room to room, deviated several feet from the direct path she apparently was pursuing, in order to climb over the rungs of the chair, and after passing through the frame work, continued on her way. Twenty-eighth week. In the outdoor cage, Alpha rested one hand on the swing as she sat beside it, and vigorously banged the swing against the solid end of the cage. The resulting noise, as well the rhythmic swinging of the arm, may have been a feature of this activity. Thirty-seventh week. The jumping, rolling, and tumbling after a period of confinement has already been described under organized play. Forty-third week.

Bodily activity as a form of play continued through the first year, and has been subsequently observed as one of the most frequent modes of play, both as an individual expression and as a social response with other young companions.

Play and manipulation essentially social. The types of play thus far considered are activities which could be carried on either individually or in social situations. While many of the instances sighted were social in nature, such social responses were probably secondary, rather than fundamental, to the behavior pattern in question. There remain for consideration a few bits of play behavior which are primarily social in significance, although they too may be seen in non-social situations.

The first pattern consists of the threatening and attacking responses, which were noted when the observer approached the upright infant. Abruptly, the chimpanzee, with erection of the hair, beat her chest with her flexed hands; swayed from side to side, arms swinging freely before her; barked vigorously and struck the extended hand of the observer with the dorsal surface of her flexed hand. Twentieth week. This behavior, with variations appeared persistently in Alpha's relations with a pet dog, less frequently with human companions, and very prominently with other infant chimpanzees. While chiefly social in its significance, it was also observed as a mode of attack on inanimate objects.

The second pattern of social play, or perhaps better, manipulation with social import, is related to the previously mentioned interest in exploring the details of the face, hands, and arms of the infant's human companions. The characteristic chimpanzee pattern of skin dressing, in contrast to the earlier simple exploration, appeared quite suddenly when the infant saw a scab on the back of the attendant's hand. She rushed across the cage, walking erectly, arms extended in advance of the body, and then thrust the index fingers of each hand through the wire-mesh so as to bring them together on the scab which she then pinched and prodded. Erection of the hair and smacking of lips and tongue accompanied the manipulation. Later the lips and tongue were used for examination of the scab. The complete pattern of behavior was strikingly similar to that of the adult chimpanzee, and occurred before this animal had had experience with creatures of its kind. Thirty-ninth week.

Social behavior

Many of the items which properly should be included under the classification of social behavior have already been considered in the discussion of vocalization, play and exploration, and emotion. The purpose of this section is to amplify and summarize these scattered observations.

Responses to humans. The earliest stage in social behavior was characterized by responses of approach and withdrawal. Approaching, i.e., raising the head, first appeared when Alpha saw

her attendants above her crib with the nursing bottle, and subsequently appeared when they came to the crib in other than feeding situations. Later she explored the features and clothing of whatever person picked her up; answered a simulated chimpanzee call from the adjoining room; and definitely transferred her interest from one observer to the other when the latter approached. When Alpha was old enought to sit and to stand with support, she arose as people entered the room and barked a greeting, and when necessary, definitely maneuvered the loose canvas cover of her crib in order to watch the human activities about the room. As soon as she was able to walk, even poorly, she turned and came from the opposite end of the crib to the attendants. Withdrawal occurred chiefly as temper tantrums when she was so handled that her movements were restricted. *Predominately second through fifth months*.

This period of relatively simple approach and withdrawal gradually passed into a more complex phase in which the infant's behavior made a more definite contribution to the social situation. Thus, we note the development of threatening, swaggering, beating on the chest, wrinkling the face, barking, and striking the observer's face or hands in friendly approaches. The above behavior is characteristic of older animals in a variety of situations, although in Alpha at this time it appeared only in playful situations. Jumping up and down exuberantly in her crib when the attendants talked to her was also noted in this phase. Her response to a stranger's hand, offered under conditions of relative security for Alpha, was interesting in this connection since it showed a gradual shift from timid to playful behavior in a social situation (see emotion, p. 70). Subsequent to fifth month.

Definite recognition of familiar attendants, and differentiation of them from strangers, was a significant feature of Alpha's social responses after the fifth month, and was accompanied by an increased social dependence upon the attendants. Thus, when she was abandoned in the yard she rushed after them and became angry if she failed to reach them. Both in the house and in the yard Alpha followed the observers more closely, with less independent exploration, and evinced a clear preference for being

carried rather than being led by hand. When visitors were present, Alpha was timid and clung to her attendants, although at the same time she showed interest in and responded to the strangers. A further indication of this closer social relation with humans was seen in her more frequent temper tantrums when she was restrained from climbing into people's laps, or when she was returned to her crib after a period of play. Other aspects of this dependence on human companions have been cited in relation to play and exploration.

Alpha's responses to a thirteen-month-old human infant are of interest. She regarded him as soon as he was placed near her on floor, walked to him when he started to crawl, barked, and followed him, stopping when he stopped. She attempted to examine his shoe with her teeth and reached for his suit with her hands and mouth. When the human infant brushed Alpha's face with his hand, she shut her eyes but made no attempt to withdraw. In their rather poorly organized efforts to play with kitchen utensils, the human infant was definitely the leader, although Alpha examined the articles and struck them with her hand. In general her behavior was interested, mildly aggressive, and gentle. Alpha's experiences with a human infant were few and of brief duration, and do not, of course, give an adequate indication of the complex social relations which might develop with prolonged stimulation. Twenty-second week.

After the eighth month the social environment of the infant chimpanzee was considerably changed by her being kept exclusively at the Station. When taken out of the cage, Alpha tumbled, jumped, and played about the room, but always returned to the attendant as the center of her activities. The introduction of a chimpanzee companion during the last two months resulted in a gradual weakening of her social dependence on humans, and the development of an intense attachment to young creatures of her kind.

Responses to chimpanzees. The absence of opportunity for active social intercourse with other chimpanzees during the first eight months, and the relatively limited contacts thereafter, have already been indicated. Alpha's early responses to the calling of

the older chimpanzees has been described under vocalization. During the time that Alpha played in her outdoor cage at the Station, although within visual range of the adult animals, her behavior did not appear to be modified by such long-distance association. Hence, the bringing together of Alpha and the infant chimpanzee, Bula, probably constituted Alpha's first real social experience with another of her kind.

Bula, an infant recently acquired from the Abreu colony, was taken from her mother, and on the same day placed in the crib with Alpha. Obviously ill-at-ease in the strange surroundings, Bula was quickly intimated by Alpha, who aggressively approached, hit at, and tried to bite her. Bula's screams and retreat only excited Alpha to further attack, and it was deemed inadvisable to quarter the animals together until they were acquainted with one another under less strenuous conditions six weeks later. At this later time the infants were housed in adjoining cribs in the nursery at the Station for two weeks; and although Alpha and Bula watched each other closely, and tried to touch one another by thrusting their fingers through the wire of the cages, their activities continued to be centered upon their attendants rather than upon each other. Forty-second to forty-fourth week.

The two infants were kept together for the first time over a prolonged period in a large indoor play cage. While Bula was being fed her breakfast Alpha was brought into the cage and given her bottle. As she entered, Alpha reached out to touch Bula, who made no overt response. Both infants finished their morning meals before further contact. Alpha then approached Bula, gently touched her, and turning her back, pushed and rubbed against Bula who had retreated to a corner. Alpha was aggressive but not rough; Bula continued to retreat. At noon Alpha took Bula's cracker, and during the afternoon kept Bula at the top of the cage most of the time. By late afternoon Alpha needed only to point her finger at Bula to have her retreat up the side of the cage, an activity which Alpha apparently enjoyed. During the ensuing week, Alpha, although still the aggressor, allowed Bula to eat without interference. An interesting modification of Alpha's response to humans occurred at this time in that she,

similarly to Bula, whimpered and sought human contacts at the slightest provocation. Forty-fifth week.

The infants were at this time transferred to adult quarters, consisting of an inner living room and an outside cage, and adjoining the quarters of four chimpanzee children. In these new surroundings Alpha continued to be the aggressor, although once Bula took the opportunity to pull Alpha's hair while she was asleep. Soon Bula fought back, maintained her food rights, and successfully challenged Alpha. Forty-sixth week. Aggressive attack by Alpha was replaced by passive acceptance of Bula's embraces. Further growth of the attachment between the two infants was seen in Bula's distress at Alpha's removal from the cage and her welcome upon Alpha's return. Later, Bula actively resisted being separated from Alpha, and when frightened by thunder, ran to her in headlong flight. Forty-seventh through fiftieth weeks.

The end of Alpha's first year of life witnessed the appearance of a close mutual dependence between herself and Bula, a social relationship in which the presence of human attendants became of secondary importance. The following instance illustrates the extent of this development. Bula, who had started to eat her breakfast in the outside cage, suddenly left her food, went inside and returned with Alpha, who remained in the doorway while Bula went back to her cup of milk. Alpha stumbled, fell on the step, and whimpered; Bula again left her food, ran to Alpha and comforted her in a mutual embrace. Fifty-second week.

Alpha's first responses to the chimpanzee children when quartered next to them varied from challenging to timid behavior. She called to them, climbed the wall to see them, and sometimes retreated when they came too close; at other times she frightened them away by shouting and beating the wall. When she was carried around to view the adult animals she showed neither interest nor fear.

Chimpanzee and human: The Gesell tests

It is perhaps fitting that the last pages of Alpha's story be devoted to a comparison of the behavioral development of this

infant chimpanzee and that of the human child. Any attempt to take such a step immediately reveals difficulties and defects. In order to make this comparison as objective and as truly comparable as possible, the writers have tried to evaluate their observations in terms of the clinical standards published by Gesell (1928) in "The Mental Growth of the Pre-School Child." A brief statement of the chimpanzee's responses to various items of the Gesell materials is given in Appendix A. The reader is also referred to the preceding sections on behavioral development for further illustrative material.

Three important factors enter into such an evaluation in terms of human standards, and of course, condition subsequent interpretations. First, structural differences between chimpanzee and human predispose the chimpanzee toward certain modes of response, and therefore make necessary certain substitutions, i.e., in the motor sequence walking on all fours was regarded as equivalent to creeping. Similarly, responses to the prehension tests have undoubtedly been modified by the poorly developed chimpanzee thumb. Consequently, the major emphasis must be on the pattern of development rather than the time at which any given item was passed. Second, there was lack of training in certain activities to which human infants are ordinarily subjected in their routine living. Although Alpha was under intensive observation, she nevertheless received much less attention than the usual human child. Third, we do not know the extent to which the subjects are motivated in these test situations. A summary of the more striking likenesses and differences is presented below.

Motor development. In the tests of postural control and locomotion, Alpha was equal to or materially accelerated over the human child. No essential test items in this group were omitted or failed.

In the simpler prehension test Alpha did not appear to be retarded, but neither was she accelerated. In more complex situations, throwing objects to the floor, or putting a cube in a cup, Alpha was definitely retarded, and she failed to toss a ball in a box or to scribble. Subsequent tests were either failed or inapplicable.

Language. The vocalization of the chimpanzee was not, in its

essential features, comparable to that of humans. Comprehension under the limited training afforded Alpha was greatly restricted.

Adaptive behavior. In the relatively simple tests of eye-hand coördination Alpha was equal to or slightly accelerated over the human child. It is interesting to note that the extent of this acceleration was much less than the acceleration on the postural and locomotor items.

In the tests involving imitation of the examiner, Alpha failed completely in the first year, and succeeded in passing only the simplest items in the second year.

Personal-social behavior. On those tests in this group which Alpha passed, she showed neither acceleration nor retardation, but, as in the adaptive behavior group, a large number of items were failed. In the play responses Alpha's behavior notably broke down on those items which called for exploitive use of the materials, and she succeeded in only the simpler of such situations.

Three significant points stand out in the analysis of the chimpanzee's responses when they are compared with those of the human infant. (1) Although the chimpanzee passed many test items at the lower age levels, toward the end of the year she had reached a point beyond which she made but little progress. The absence of language did not appear to be the immediate cause of such failure since numerous non-language tests involving imitation and exploitive behavior were failed. Examination of Alpha in the second year, and incidental observations on older chimpanzees, have indicated that within marked limits the chimpanzee is capable of performing additional test items but only after greater experience and development. (2) Among the test items which were passed, the temporal sequence in which they were accomplished followed rather closely the order for the human infant. (3) In the tests of postural and locomotor development which Alpha successfully met, she was greatly accelerated over the human infant; in the majority of other test situations which were passed she tended to maintain about the same age level as the average human child.

Any attempt to make extensive interpretations or to give a

quantitative expression to relative developmental levels or rates on the basis of these data would obviously be out of place. In spite of the many striking instances of similarities which have been pointed out between this chimpanzee and the human infant, and in spite of the "almost human" attachments established between this baby and her observers, the indubitable fact remains that Alpha and the human infant are not quite like Judy O'Grady and the Colonel's lady, "sisters under the skin."

APPENDIX A

RESPONSES TO GESELL NORMATIVE ITEMS

The test items are presented as given in "The Mental Growth of the Pre-School child" by Gesell (1928). The key number (M 10) is followed by a descriptive phrase (Resists Head Pressure); by the month and letter ratings (4C); by a brief statement of Alpha's responses, if necessary; and finally, by the time at which the item was passed by the chimpanzee (First week). The significance of the month and letter ratings is quoted from Gesell. "A+ represents a frequency of 1 to 19 per cent; A equals 20 to 49 per cent; B+ equals 50 to 64 per cent; B equals 65 to 84 per cent; and C equals 85 to 100 per cent." The percentages refer to the per cent of human children passing a given test item at the indicated age level.

NORMS OF MOTOR DEVELOPMENT

Postural control

M 10 Resists Head Pressure

4C First week.

M 11 Holds Head Erect.

4B Alpha maintained erect head posture when placed in various positions. Second week.

M 12 Lifts Head in Prone Position.

4C Third week.

Lifts Head and Chest.

4B Seventh week.

M 13 Back Resistant.

This response was observed in the routine care of the infant.

First week.

M 14 Tries to Sit Up.

4C Attempted to sit up when approached with bottle. Fifth week.

6A+ Sat alone for brief period. Twelfth week.

M 15 Stands.

As soon as the infant was able to sit alone, she also stood on all fours. Twelfth week.

12A Stood erectly without support. Twenty-seventh week.

Locomotion

M 20 Reactions when Prone.

4C Squirmed forward, pushing with her feet. Third week.

6A+ The infant was not observed to creep, but as indicated in motor sequence walked on all fours. Thirteenth week.

12B Climbed cage and chairs. Twenty-fourth week.

M 21 Rolls from Side to back.

Omitted.

M 22 Rolls from Back to Stomach.

4A+ In rolling from back to stomach, the infant grasped foot with hand of same side, and kicked with free limbs until she rolled over. Tenth week.

M 23 Motor Reactions in Bath.

Omitted. Sponge baths substituted for tub.

M 24 Pushes with Feet.

Not adequately tested.

M 25 Makes Stepping Movements.

Not adequately tested.

M 26 Walks.

Walked on all fours. Thirteenth week.

9A+ Walked erectly with support from furniture. Seventeenth week.

12A Walked erectly without support. Twenty-ninth week.

Prehension

M 30 Resists Rod Withdrawal.

4C Not adequately tested, although infant grasped and held object pressed lightly against the palm a few days after birth. First week.

M 31 Clasps Cube.

4C Alpha refused to accept cube placed in palm of the hand, although she grasped and carried to her mouth various small objects in the crib. Ninth week.

M 32 Hands React to Table Edge.

4B Not adequately tested before the third month when the infant fingered the table top but did not pat it.

M 32 Picks up Cube.

4A+ Alpha regarded the cube but did not reach for it during the third or fourth months; later, tried to grasp cube with her mouth, and when prevented, corralled it with her hand. Twentieth week.

Grasps cube with fingers only and carried it to her mouth. Twenty-third week. The side of the thumb was used in picking up the cube and reaching was more direct, Twenty-seventh week; and from now on, the thumb was used in a variety of positions. Clear-cut and sustained thumb-fingertip opposition was not noted in this test until the second year.

M 32 Secures Pellet.

6A Alpha regarded the pellet, Fourth month; corralled it with whole hand, Twentieth week; fingered it with index finger, Twenty-fifth

week; fingered it with both index fingers, Twenty-ninth week; and picked up pellet between the second and third fingers and carried it to her mouth, Thirtieth week. Subsequently to this success the infant picked up the pellet in a variety of ways: between dorsal surface of thumb and index finger, between the inner surfaces of the fingers, and in a squeeze grasp between the tips of her fingers and the palm of the hand. It was not until she was tested at the fifteenth month that she consistently used the tip of her index finger and the thumb in a variety of positions. It was not possible accurately to date this development, since in the shift of experimenters and animal to the New Haven Laboratories no tests were made between the tenth and fifteenth months.

M 33 Hand to Mouth Reaction.

4C The hand was frequently brought to the mouth in thumb sucking,

First week, and later objects which she grasped were brought to
her mouth. Seventh week.

12B At eight months Alpha handled the doll without putting it in her mouth, although most objects were usually examined with lips, teeth, and tongue. It was not until the fifteenth month that this hand to mouth response, although still persisting, was significantly reduced in frequency. Fifteenth month.

M 34 Uses One Hand.

Not tested early enough to be significant.

M 35 Holds Two Cubes.

At no time could Alpha be induced to accept a cube when it was placed in her hand; hence in testing, she was shown a second cube, held before her or placed on the table, after she already had a first cube in her hand. The first positive response to two cubes was seen when the infant moved one of two cubes

two cubes was seen when the infant moved one of two cubes exposed on the table, then moved the second to the first, and attempted to mouth both at once. Twenty-sixth week. She grasped one cube in her left hand, held it to her mouth, then grasped the second cube with her right hand, and in five seconds, dropped the first cube to finger the second. Twenty-ninth week.

M 35 Accepts Additional Cube

6B+ Alpha grasped one cube in her left hand, then took a second cube in her right hand, dropped the first cube to finger the third, then dropped the second and grasped the third. Later, she grasped one in her left hand, a second in her right, then dropped the first and took the third. Thirtieth week.

9A The infant accepted a third cube with her mouth while holding one in each hand. Thirtieth week.

18B Failed to accept fourth cube.

M 36 Throws Objects to Floor.

6A Brushed aside nursing bottle when finished, Twelve weeks; rarely threw objects down otherwise. In the second year she bounced the ball and dropped the doll frequently. Fifteenth month.

M 36 Puts Cube in Cup.

During the first year Alpha failed this test possibly because of lack of attention to cube whenever the cup was present. Later, after watching the experimenter, Alpha put the cube in the cup without releasing her hold, removed the cube, then put it back in the cup and released it. She then took it out and put it in her mouth. Fifteenth month. Three months later Alpha played by repeatedly putting the cube in the cup, releasing it, and subsequently removing it. Eighteenth month.

M 36 Tosses Ball in Box.

Failed test.

Drawing

M 40 Scribbles.

9A+ Alpha grasped and brought the crayon to her mouth, Twentythird week; there was no attempt to scribble or to bring the
crayon in relation to the paper, nor any clear indication that
she observed the marks made on the paper by the examiner.
In the second year she observed the motion of the crayon,
Fifteenth month; and took the pencil away from her mouth when
the examiner said "no, no," picked it up and put it on the paper
so that the writing end rested on the paper without attempting
to write. She put her finger on the scribbled marks. Eighteenth month.

M 41 through M 48, complex drawings, were failed.

NORMS OF LANGUAGE DEVELOPMENT

Vocabulary

L 10 Vocalizes.

4B The fear-anger cry, the chimpanzee bark which appeared in the ninth week, and whimpering in the twelfth week, constituted Alpha's chief forms of vocalization. These responses do not appear to be comparable with the type of vocalization shown by human infants

L 11 through L 17, vocabulary tests, were failed.

Comprehension

L 20 Adjusts to Words.

9B+ Non-verbal response to spoken commands was noted when Alpha stopped biting the furniture at the command "no, no."

Twenty-sixth week. Later, she inhibited the biting response and substituted manual examination. Thirty-first week.

L 21 through L 46 were failed.

NORMS OF ADAPTIVE BEHAVIOR

Eye-hand coördination

A 10 Eyes Follow Moving Person.

4C The infant followed the attendant's movements with her eyes, turning her head as he left the room. Sixth week.

A 10 Follows Moving Plate.

4B Alpha followed the moving plate in all directions. Ninth week.

A 11 Blinks at Sharp Sound.

4C Blinking and auricular twitching. First week.

Winks at Threatening Hand.

4B Tenth week.

Winks at Pencil.

4A Eighteenth week.

A 12 Reacts to Paper.

4A Alpha made definite defensive movements in pushing the paper from her face. Not tested sufficiently early. Eighteenth week.

A 13 Regards Spoon or Cube.

4A Regarded spoon and cube without reaching for them. Eighth week.

Perceives Pellet.

6B+ Eighteenth week.

A 14 Picks Spoon from Table.

4A+ Alpha mouthed the spoon. Nineteenth week; corralled it, twentieth week; and picked it up with her thumb doubled under.

Twenty-third week.

A 15 Reacts to Dangling Ring.

4C Tenth week.

Attends Dangling Ring.

4A Alpha seized the suspended ring and brought it to her mouth, 6B and seized the ring while she was seated on the examiner's lap. Fourteenth week.

A 16 Reaches for Spoon.

Omitted.

Imitation

A 20 Imitates Rattle of Spoon in Cup.

9A Failed until the second year when Alpha put the spoon in the cup, Fifteenth month; and later put the spoon in the cup and moved it around. Eighteenth month.

A 21 Rings Bell.

9A Alpha grasped the handle, later played with the clapper, but never rang the bell.

A 22 Rubber Doll Imitation.

12A Alpha manipulated the doll, and at times elicited a few squeaks, but never showed clear imitation of the examiner's behavior.

A 23 Block Building.

12B+ Alpha made no attempts at block building during the first year.

The examiner's tower was struck down for the first time,

Fifteenth month; while three months later the infant made a
two block tower and a three block tower. Eighteenth month.

A 24 through A 27 were failed.

Recovery of objects

A 30 Looks for Fallen Spoon. 6A Twenty-sixth week.

A 31 Cup-covered Cube Test.

6A+ The infant picked up the cup, but paid no attention to the cube, Failed.

A 32 Unwraps cube. 9A+ Failed.

A 33 Removed Pellet from Bottle.

12A Failed during the first year, and later learned in the test situation to tip the bottle over to secure pellet. Fifteenth month.

A 34 through A 74 were failed.

NORMS OF PERSONAL-SOCIAL BEHAVIOR

Reactions to persons

P 10 Adapts to Nursing. 4C First week.

P 11 Attention to Face.

4B Examined features of face. Thirteenth week.

6B+ Differential response to strangers. Twenty-third week.

P 12 Anticipatory Motor Adjustments.
Omitted

P 13 Reaction to Mirror.

Alpha looked in the mirror but made no other response, Twenty-first week; fingered the edge of the mirror, and twice while looking in the mirror turned suddenly and clung to the examiner, Twenty-sixth week; looked directly at her eyes in the mirror, upward and to the sides, then back to the center, and touched the image with her finger, Thirty-first week; and later, tried to reach behind the mirror, and lifted it from the wall. Thirty-fifth week.

P 14 Salutations.

9B+ Failed, although sporadic attempts to have Alpha wave bye-bye were made.

P 15 Shows Affection Spontaneously.

18A No satisfactory judgment could be made on this item.

P 16 Forbidden Acts.

18B Passed, see L 20. Twenty-sixth and Thirty-first weeks.

P 17 through P 21 were failed.

P 22 Bowel Control. P 23 Bladder Control.

No attempts were made to train Alpha in these habits.

P 24 through P 30 failed.

P 31 Persistence in Reaching.
6A Twenty-ninth week.

P 32 and P 33 were failed.

P 34 Climbs for Object.

18A Alpha climbed to the top of a chair for her milk bottle which had been placed on the table out of her sight. Thirty-first week.

P 35 through P 38 were failed.

Play behavior

P 40 Playful Reactions.

6B+ Alpha played and frolicked with the observer although she was never observed to smile. Fifth month.

P 41 Early Play.

4C Played with her hands. Eighth week.

4B Scratched crib. Ninth week.

4B+ Played with objects. Third month.

6B Patted table. Twentieth week.

6A Threw objects for play. Rarely observed.

6B Exploited paper. Eighth week.

9A+ Puts cube into cup. Failed.

P 42 through P 56 were failed.

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PLATE 1

Upper: Alpha as she appeared three hours after birth. Lower: Nursing, third day. (Photographed by Tinklepaugh.)





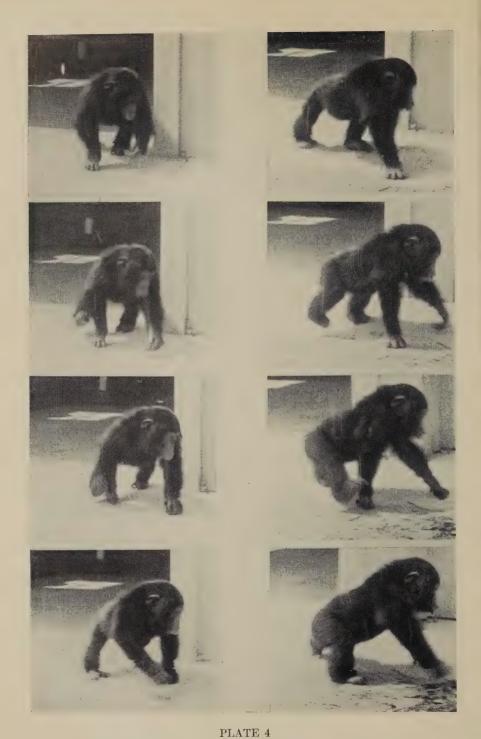
PLATE 2

Upper: Alpha has grown, sixth week. (Photographed by Yerkes.) Lower: Reaching for her bottle, fourth month. (Photographed by Tinklepaugh.)



PLATE 3

Upper: Thumb sucking was sometimes an emotional outlet, fifth month, and A profile, sixth month. Lower: Examining the bark of a tree, and Just sitting, seventh month. (Photographed by Yerkes.)



Running and calling; note the puckered lips, sixth month. (Photographed by Yerkes.)

INDEX

Allesch, G. J. von, 48, 88	Feces, 39
Atwater, W. C., 6	Foods, list of, 10
D' 1 II C 9 4	responses to, 11
Bingham, H. C., 3, 4	C
Birth, account of, 7	Gesell, A., 57, 79, 82, 88
physiological state at, 21	Grasping, see reaching
Blood, cell count, 39	Growth, physical, 12
Broadbent, B. H., 6, 14	behavior in relation to, 52
Buchman, T. E., 10	rate of, 15, 16, 18 summary of, 19
Companionship, chimpanzee, 9, 77	summary of, 19
human, 9, 75	Habitat, 7
Comparison of chimpanzee and human	Halverson, H. M., 60, 88
dentition, 12	Health, 11, 12, 38
Gesell tests, 60, 79, 82	physical growth, in relation to, 15, 18
limitations in, 80	Holloway, L., 6
motor sequence, 50, 80	,
reaching and grasping, 60	Imitation, 81, 88
skeletal development, 19	
Coprophagy, 12	Learned, B. W., 62, 88
D 1'1' 10	A
Dentition, 12	Manipulation, see reaching
Development, behavioral, 40	Measurements, anthropometrical, 24
environment, influence of, 40, 48, 80	Morford, H. S., 7 Motor sequence, 43, 80
patterns and sequences of, see	comparison with chimpanzees, 48
special topics	comparison with human infant, 50
summary, cross-sectional, 41	skeletal development, relation to, 52
physiological, 20	22020002 40 (020 p-110-10) 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
summary of, 39	Nissen, H. W., 6, 23, 62, 88
Dietary, 10	, , , , ,
	Ornamentation, 73
Emotional behavior, 63	Ossification of epiphyseal centers, 18
anger, 67	behavior in relation to, 52
thumb sucking, 68	
	skeletal age, 19
excitement, mild, 70	skeletal age, 19
compared with "love," 71	skeletal age, 19 P/R ratio, 29
compared with "love," 71 fear, extreme instance of, 64	skeletal age, 19 P/R ratio, 29 Parentage, 3, 7
compared with "love," 71 fear, extreme instance of, 64 snake, absence of fear for, 65	skeletal age, 19 P/R ratio, 29 Parentage, 3, 7 Play and exploration, 71, 88
compared with "love," 71 fear, extreme instance of, 64 snake, absence of fear for, 65 timidity, 69	skeletal age, 19 P/R ratio, 29 Parentage, 3, 7 Play and exploration, 71, 88 opportunities for, 8
compared with "love," 71 fear, extreme instance of, 64 snake, absence of fear for, 65	skeletal age, 19 P/R ratio, 29 Parentage, 3, 7 Play and exploration, 71, 88

94 INDEX

Reaching, grasping and manipulation, 54, 83
comparison with human infant, 60
Gesell normative items, 57, 80, 83
index fingers, use of, 55, 59, 75
manipulation as play, 75
mouth, use of, 55
thumb opposition, 58
thumb sucking, 54
Recognition of people, 76, 87
Reflexes, original, 20
Respiration, 28

Shaw, W. M., 6 Sherman, J., 67, 88 Shirley, M. M., 50, 88 Skin dressing, 75 Snake, absence of fear for, 65 Social behavior, 75, 87 Temperature, 22
Thompson, H., 6
Threatening, as play, 75
Thumb sucking, when hungry, 12
reaching in relation to, 55
as substitute response, 68
Tinklepaugh, O. L., 3, 4, 5, 7, 11, 88
Todd, T. W., 6, 19, 54

Urine, 39

Vocalization, 60, 70 verbal commands, 62, 85 vocal play, absence of, 61

Weight, 16 White, B., 48, 88

Yerkes, A. W., 48, 62, 67, 88 Yerkes, R. M., 1, 5, 7, 8, 48, 62, 65, 67, 88 Vol. 9 No. 2

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STUDIES IN CONCEPT FORMATION

BY

PAUL E. FIELDS

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STUDIES IN CONCEPT FORMATION

I. THE DEVELOPMENT OF THE CONCEPT OF TRIANGULARITY BY THE WHITE RAT

PAUL E. FIELDS

National Research Council Fellow, Stanford University

CONTENTS

I. Introduction	2
II. Apparatus	6
III. Animals	14
IV. Technique	15
Preliminary training	15
Incentives	16
Series Order.	17
Scoring of Trials	18
V. Experimental Section.	19
Experiment I. Discrimination between triangle and circle	20
Experiment II. Discrimination between figures of unequal area	23
Experiment III. Positive versus negative reaction	27
Experiment IV. Reaction to new brightness relationships	31
Experiment V. Reaction to new positions of the triangle and	
strange figures	34
Experiment VI. Discrimination between new positions of the	
triangle and a circle	36
Experiment VII. Retest of reaction to new triangle positions and	-
other figures	44
Experiment VIII. Test for the "concept" of triangularity	50
Experiment IX. Training and test of reactions to triangles and	
circles in new brightness relationships	55
VI. Discussion.	61
VII. Summary	65
III. Conclusion.	69
References	69

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The program for this research was outlined while at Ohio State University and is intended to continue a series which we began in 1926. The data to be presented were collected in 1930–1932 during the tenure of a National Research Council Fellowship in the Department of Psychology at Stanford University. All expenses of the study have been met from the Thomas Welton Stanford Fund.

I am greatly indebted to the late Dr. A. P. Weiss for the suggestion that it might be possible to find some specific muscular reaction of the rat which, under experimentally controlled conditions, would serve as an indicator of what was going on within the rat's body in much the same way that a man's language response serves us.

I wish to express my appreciation of the assistance given by Dr. C. P. Stone in providing the materials, animals and the necessary experimental rooms for this study. I am also indebted to Dr. K. S. Lashley for furnishing me with the drawings for his jumping apparatus before they had appeared in print. Mr. Michael Tomilin and Dr. C. Ray Carpenter were present and observed the reactions obtained in many of the critical test situations of the experiment.

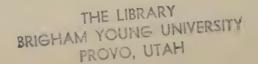
A preliminary report of this work was made before the Western Psychological Association at the University of Oregon in June 1931, and a more detailed paper was presented at the Toronto meeting of the American Psychological Association. The writer has also profited from a reading of the original manuscript by Dr. C. P. Stone, Dr. Paul Farnsworth and Dr. K. S. Lashley.

I. INTRODUCTION

Since the earliest studies on form discrimination these questions have probably been asked most frequently:

Even though we were to grant that the white rat is able to discriminate an equilateral triangle, apex up, from a circle of equal area and brightness, would this discrimination be based upon the rats' recognition of the qualities of triangularity (three sides and three angles) as opposed to the qualities of circularity (all points on a curved line equidistant from the center)? Or, are the rats merely reacting to a differential retinal distribution of light without any reference to the qualities inherent in such distributions?

Although there is a lengthy discussion of "form" perception under the varying titles of form, shape or pattern discrimination in the literature of 1912–1914, no one was successful in answering the questions contained in the previous paragraph, so far as the white rat was concerned, because they were not able to establish the primary discrimination between geometrical figures of equal area and brightness. But relatively recent developments in apparatus and technique have solved this initial problem (see 7) and have opened the way for studies with a wider degree of interest. We shall refer to these studies only in so far as they deal with the question of abstraction or concept formation, and will discuss them in their most appropriate connections with this experiment.



If the rat reacts to "triangularity" then we might imply that it is capable of exhibiting a type of behavior, which, had it occurred in man, would be more or less accurately represented by a composite of such terms as abstraction, generalization, concept, idea, perception, image and meaning. In traditional psychology all of these terms have presupposed some sort of non-biological factor and are so intimately bound up with the language responses of human psychology that any attempt to use them as categories for the classification of animal behavior has met with resistance.

But the recent emphasis upon psychology as a biological science in which "the so called psychical conditions can only be adequately studied as movements (in contractile elements) of such magnitude that they may act as stimuli and release responses in others" (15, p. 167) has given us the opportunity to use these terms with reference to the observable behavior of a rat in relation to its environment.

I wish to paraphrase a statement taken from Hull's "Evolution of Concepts," substituting "triangle" for "dog."

A young child finds himself in a certain situation (white equilateral triangle, apex up, area of 28 sq. cm.), reacts to it by approach, and hears it called "triangle." In a somewhat different situation (white equilateral triangle, apex down, area of 28 sq. cm.) he hears that called "triangle." Later in a still different situation (black equilaterial triangle, rotated 30 degrees, area of 56 sq. cm.) he hears that called "triangle" also. There is no obvious label as to the essential nature of the situation, which precipitates at each new appearance a more or less acute problem as to the proper reaction. And so the process goes on with right angle, isosceles, and scalene triangles until the day finally comes on which the child makes the specific language response "triangle" whenever any of the foregoing classes of figures are presented. The child now has a meaning for the shape "triangle." Upon examination this meaning is found to be actually a characteristic more or less common to all triangles and not common to squares, circles, etc. But to the child the process of arriving at this meaning or concept has been largely unconscious. The formation of the concept has never been an end deliberately sought for itself. It has always been the means to an end,—the supremely absorbing task of physical and social reaction and adjustment (9, p. 5).

If Hull is justified in using the term "concept" to denote the observable behavior of a child when it makes a specific language response to a certain stimulating situation, then we should be allowed to use the term "concept" to denote the observable behavior of a rat when it makes a specific muscular response to a similar stimulating situation. The difference seems to be one of degree, not of kind, in that it is necessary for the rat to use less complex reaction units than the child. But so far as the present study is concerned, the specific acquired reaction involved in the "jump to triangle" of the rat will be considered as equivalent to the child's specific language response "triangle."

That Hull would not be averse to our substitution of a specific muscular reaction for the language response is indicated in his comparison of the "candle-glowing electric light bulb situation" with the three "steps" of formal instruction originated by Herbart. The first distinction listed is, "A linguistic reaction replaces the protective." In other words, the withdrawal of the hands from the light (protective movement of the child) has been replaced by a language response, but both are outward manifestations of the generalizing abstraction which had already taken place.

There are at present two conflicting ideas with respect to con-(1) The most popular one assumes that the concept is present in man ready-made, and that it is to be regarded as some kind of a mental capacity ready to function at any time. similar to an "all or nothing" principle, in that, if the capacity is not present at first, no amount of training will be effective in producing it. (2) The second theory assumes that each individual (infra-human included) has evolved his own concepts, and that there must necessarily be a period during which the experiencing organism develops the concept. This idea of course takes away some of the prestige that would otherwise belong to man, but it opens up the possibility of an experimental approach by means of which the behavior of various animals may be rated on a scale according to the speed with which certain specific reactions are established, or according to the complexity of the ultimate behavior pattern.

In support of this second theory we find in the experimental

literature that individuals are able to react successfully to new situations if they are sufficiently similar to those of the original training period, but that the reaction was not successful in the first few trials even though the capacity for doing so (as evidenced by later perfection of the response) must have been present from the beginning. The explanation for this has been attributed by Gengerelli to training in the perception of "identical existential elements" in the two situations (8). But there has been a feeling that this explanation is too simple and does not take into account the more numerous cases in which the individual is able to react successfully when the similarity between the training and the test situation is something more than the mere presence in both of identical elements. This perception of "identity in diversity" has been vaguely connected with the idea that the organization of an object of experience is more important and comes before its more existential characteristics. If there is a difference between man and the other animals in the development of concepts, then it should be apparent in a test situation where the successful response is dependent upon the total organization of the stimulus pattern rather than the nature of the elements of which it is composed. It should be possible to devise such a test situation.

With the introduction of the Lashley jumping type of apparatus and the very rapid learning reported there (12), we thought it desirable to repeat certain of our earlier experiments with this new instrument to see whether results obtained from the running and jumping types of apparatus were comparable. Thus the principal problems which it is our purpose to investigate are as follows:

- (1) In the words of Dr. A. P. Weiss, "Does the white rat have a specific reaction for a particular form which is comparable to that of a man's vocalization 'triangle'?" If the rat is found to have such a specific reaction, does it carry over to situations in which the total organization of the stimulus pattern is more important than the elements of which it is composed?
- (2) Is the essential nature of the discriminative response obtained with the jumping apparatus similar to that obtained on the running type of apparatus?

In addition to these, certain problems which are supplementary to the main issue but easily investigated under the same conditions will be given consideration.

II. APPARATUS

The apparatus which we used throughout the course of these experiments is illustrated in figure 1. It is similar to the jumping apparatus described by Lashley (12), but with the following changes:

- (1) The inter-hole distance was increased from 2 to $4\frac{1}{2}$ inches.
- (2) The tin flange over these holes was increased from 12 to 18 inches.
- (3) The circular jumping stand was replaced by a rectangular platform 10 by 18 inches; a wire ladder (made of two thicknesses of ½ inch hardware cloth) 3 by 20 inches was suspended from the middle of the rear surface of this rectangular platform and sloped upward at an angle of 85 degrees. The rat was put on the bottom of this ladder after each jump instead of on the surface of the platform.
- (4) Instead of using daylight for illumination, the apparatus was set up in a dark room and the figures were illuminated by a 25 watt lamp which was put in a small box and fastened to the stem of the platform (a 2- by 4-inch board) in such a manner that the two holes were equally lighted, but so that the rat's shadow would not fall on the figures as he stretched out toward them. The open side of the box facing the figures was covered with two thicknesses of black Hawthorne bunting to cut down and diffuse the light.
- (5) The entire apparatus was painted a dead black, and the sides, top, and front (between the jumping platform and the experimenter) was carefully screened by two thicknesses of black Hawthorne bunting. Since the only light in the room was on the stem of the jumping platform (inside the screen) and was directed forward against the figures, it was difficult for the rat to observe any movement outside of the curtains.

(6) The apron into which the rat fell after making a jump to the non-standard figure was made of black bunting and extended from the main apparatus to a bar fastened on to the stem of the jumping platform.

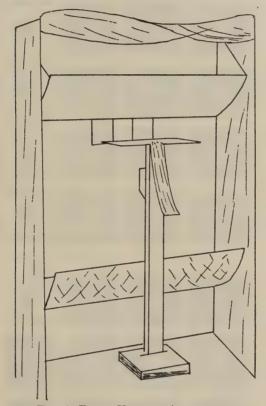


Fig. 1. Front View of Apparatus

The screen is a three ply wood panel 4 by 6 feet. The two openings in which the forms are exposed are 6 inches square, separated by $4\frac{1}{2}$ inches, and are 4 feet above the floor. There is a $3\frac{1}{2}$ foot drop from the bottom of these openings to the apron below. The metal flange above these holes extends forward and upward for 18 inches across the complete width of the screen. The food platform at the back of the holes (not shown) is 15 by 21 inches with raised edges to prevent the rat or food from sliding off.

The top of the jumping platform is 10 by 18 inches, with the long side facing the holes in the screen. A wire ladder, 3 by 20 inches was hung from the middle of the platform at an 85° angle. The light box was 3 by 5 inches, placed on the stem $4\frac{1}{2}$ inches beneath the surface of the jumping stand so that the rat's shadow would

not fall on the figures as he stretched out toward them.

The curtains at the sides and the front (shown at the top of the apparatus in the drawing) were two thicknesses of Black Hawthorne Bunting. The white apparatus was similar to the one just described except in color. White curtains were used to replace the black ones.

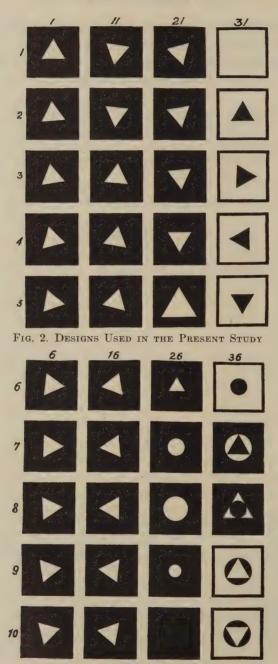


Fig. 3. Designs Used in the Present Study

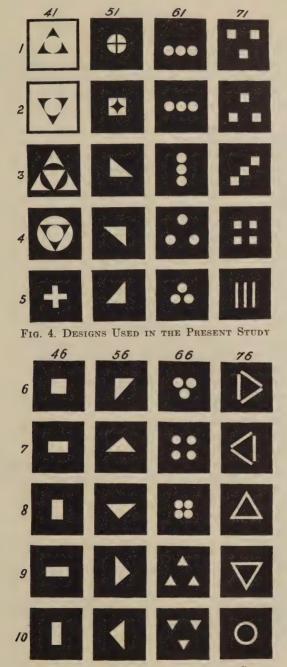


Fig. 5. Designs Used in the Present Study

TABLE 1

Description of designs used in this study

Unless otherwise stated, the areas of the figures are 27.7 sq. cm.; they are white figures on black cards; the centers of the figures are coincident with the center of the card on which they are placed; all rotated figures are rotated about this center. The cards are 7 inches high and 9 inches long.

CARD NUMBER	DESCRIPTION
1	Equilateral triangle, apex up
2	Equilateral triangle, rotated 5 degrees to the left
3	Equilateral triangle, rotated 10 degrees to the left
4	Equilateral triangle, rotated 15 degrees to the left
5	Equilateral triangle, rotated 20 degrees to the left
6	Equilateral triangle, rotated 25 degrees to the left
7	Equilateral triangle, rotated 30 degrees to the left
8	Equilateral triangle, rotated 35 degrees to the left
9	Equilateral triangle, rotated 40 degrees to the left
10	Equilateral triangle, rotated 45 degrees to the left
11	Equilateral triangle, rotated 50 degrees to the left
12	Equilateral triangle, rotated 55 degrees to the left
13	Equilateral triangle, rotated 5 degrees to the right
14	Equilateral triangle, rotated 10 degrees to the right
15	Equilateral triangle, rotated 15 degrees to the right
16	Equilateral triangle, rotated 20 degrees to the right
17	Equilateral triangle, rotated 25 degrees to the right
18	Equilateral triangle, rotated 30 degrees to the right
19	Equilateral triangle, rotated 35 degrees to the right
20	Equilateral triangle, rotated 40 degrees to the right
21	Equilateral triangle, rotated 45 degrees to the right
22	Equilateral triangle, rotated 50 degrees to the right
23 24	Equilateral triangle, rotated 55 degrees to the right
$\frac{24}{25}$	Equilateral triangle, apex down. (Inversion of No. 1) Equilateral triangle, area of 55.4 sq. cm., apex up, arranged so that the
20	base and apex were equidistant from the edges of the card
26	Equilateral triangle, area of 13.8 sq. cm., apex up
27	Circle, area of 27.7 sq. cm.
28	Circle, area of 55.4 sq. cm.
29	Circle, area of 13.8 sq. cm.
30	Plain black card. (3 finishes, paint, lacquer and india ink)
31	Plain white card
32	Equilateral triangle, black, area of 27.7 sq. cm., apex up, center in center
	of white card
33	Similar to No. 32, except rotated 30 degrees to the left
34	Similar to No. 32, except rotated 30 degrees to the right
35	Similar to No. 32, apex down
36	Circle, black, centered on white card

TABLE 1-Continued

	TABLE 1—Communea
CARD NUMBER	DESCRIPTION
37	Equilateral triangle, black, area of 27.7 sq. cm., apex up, about which was circumscribed the smallest possible white circle, centers of both figures coincident with the centre of the black card
38	Circle, black, area of 27.7 sq. cm., with the smallest possible white equilateral triangle, apex up, circumscribed about it; centers of both figures coincident with the center of the black card
39	Equilateral triangle, white, area of 27.7 sq. cm., apex up, with smallest possible black circle circumscribed about it, centers of both figures coincident with centers of white card
40	Similar to No. 39, except that apex of the inner white triangle was pointed down. (Inversion of No. 39)
41	Circle, white, area of 27.7 sq. cm., with smallest possible black equilateral triangle, apex up, circumscribed about it; centers of both figures coincident with centers of white card
42	Similar to No. 41, except that apex of the outer black triangle was pointed down. (Inversion of No. 41)
43	Equilateral triangle, white, area of 27.7 sq. cm., apex down, with smallest possible black circle circumscribed about it, which in turn had the smallest possible equilateral triangle, white, apex up, circumscribed about it. Arranged so that the entire pattern was equidistant from the edges of the black card
44	Circle, white, area of 27.7 sq. cm., with smallest possible black triangle circumscribed about it, apex down, which in turn had the smallest possible white circle circumscribed about it; centers of all figures coincident with the center of the black card
45	Cross, arms of equal length. (7.92 cm. x 2 cm.)
46	Square
47	Rectangle, base equal to altitude of the standard equilateral triangle. (6.92 cm.)
48	Similar to No. 47, except that the vertical side is equal to the altitude of the standard equilateral triangle. (6.92 cm.)
49	Rectangle, base equal to the side of the standard equilateral triangle. (8 cm.)
50	Similar to No. 49, except that the vertical side is equal to the side of the standard equilateral triangle. (8 cm.)
51	Standard white circle, area of 27.7 sq. cm., divided into quarters and separated by 5 mm. black spaces, giving the general form of a white circle with a black cross upon it
52	Quarters of the circle (No. 51) arranged so that the centers of the circles form the corners of a square, 6 cm. on a side, enclosing a black design
53	Right angle triangle, white, area of 27.7 sq. cm., (base 8 cm., altitude 6.92 cm.) center coincident with the center of the black card. Altitude parallels the left side of the card, and the base parallels the bottom

TABLE 1—Continued

CARD NUMBER	DESCRIPTION
54	Similar to No. 53, except that the base parallels the top of the card, and the altitude parallels the right side
55	Similar to No. 53, except that the base is parallel to the right side of the card and the altitude parallels the bottom
56	Similar to No. 53, except that the base is parallel to the left side of the card and the altitude parallels the top
57	Similar to No. 53, except that the hypotenuse is parallel to the bottom of the card with the base to the left
58	Similar to No. 53, except that the hypotenuse parallels the top of the card with the base to the right
59	Similar to No. 53, except that the hypotenuse parallels the left side of the card with the base at the top right
60	Similar to No. 53, except that the hypotenuse parallels the right side of the card with the base at the lower left
61	Three white circles, of equal size with a total area of 27.7 sq. cm., arranged in a horizontal line with their centers on points corresponding to each end and the middle of the base of the triangle in No. 1
62	Same 3 circles used in No. 61 arranged in a horizontal line so that the center of the middle circle coincides with the center of the black card
63	Same 3 circles used in No. 61 arranged in a vertical line so the center of the middle circle coincides with the center of the black card
64	Same 3 circles used in No. 61 arranged so their centers coincide with points corresponding to the apices of the triangle in No. 1
65	Same 3 circles used in No. 61 arranged so their centers coincide with points corresponding to the apices of an equilateral triangle 4½ cm. on a side, apex up
66	Same as No. 65, except that the triangle on whose apices the circles are placed has the apex down. (Inversion of No. 65)
67	Four white circles, of equal size and with a total area of 27.7 sq. cm., arranged so their centers coincide with points corresponding to the corners of the square in No. 46
68	The same 4 circles used in No. 67 arranged so their centers coincide with the corners of a square 34 mm. on a side
69	Three white equilateral triangles, apex up, of equal size and with a total area of 27.7 sq. cm., arranged so that their centers coincide with points corresponding to the apices of the triangle in No. 1
70	Same 3 triangles used in No. 69 inverted with their centers placed on points corresponding to the apices of the triangle in No. 24. (Inversion of No. 69)
71	Three white squares, of equal size and with a total area of 27.7 sq. cm., so arranged that the middle of their bottom side coincides with points corresponding to the apices of the triangle in No. 24

TABLE 1-Concluded

CARD NUMBER	DESCRIPTION
72	Similar to No. 71, except that the middle of the top side of the small squares coincides with points corresponding to the apices of the
73	triangle in No. 1. (Inversion of No. 71) Same white squares used in No. 71 arranged so that the left and bottom sides of one coincide with the lower left corner of a 10 cm. square; the center of the second small square coincides with the center of the 10
	cm. square; while the top and right sides of the last small square coincides with the upper right corner of the 10 cm. square
74	Four white squares, of equal area and with a total area of 27.7 sq. cm., so arranged that their centers coincide with the corners of the square in No. 46
75	Three white rectangles (9 cm. x 1 cm.) arranged vertically on a black card so that they are equidistant from the edges
76	Same 3 rectangles used in No. 75 arranged so as to form the outline of a triangle similar to that in card No. 7
77	Same 3 rectangles used in No. 75 arranged so as to form the outline of a triangle similar to that in No. 18
78	Black equilateral triangle, apex up, 8 cm. on a side, surrounded by a band of white 1 cm. wide; center of both figures coincident with the center of the black card
79	Similar to No. 78, except that the apex of the triangle is down. (Inversion of No. 78)
80	Black circle, area of 27.7 sq. cm., surrounded by a band of white 1 cm. wide; center of both figures coincident with the center of the black card

(7) There was a dish of food directly behind each card instead of one dish half way between the two cards.

The cards were seven by nine inches and made of "perfection coated" white cardboard. The figures were first drawn on them, and then the black portions were filled in with a camel's hair brush. Flat black paint (the same that was used in painting the apparatus), Higgins' India ink, and black lacquer were used, with the paint probably most satisfactory. The paint was of a consistency that flowed easily from a ruling pen and gave a smooth even surface which dried quickly and could be sponged clean with a soapy cloth. The India ink cards were rather easily disfigured, and the lacquer finish was hard to apply and chipped some. However, the kind of finish did not seem to affect the accuracy of the rats' reponses. (See figures 2 to 5 for reproduction of the designs and table 1 for their description.)

Although we will refer to the cards by their number, for example, card 1 (white equilateral triangle, apex up, area of 27.7 sq. cm.), what we really mean is that the *design* and not necessarily the identical card was exposed in the apparatus. Many different cards with identical designs were used throughout the study, and in several instances the identical card (since it could be inverted) would be used for two different designs. The positive and negative cards were stacked on top of one another and held down by a weight while not in use in the apparatus. These precautions were taken to reduce the possibility of the rats reacting to some peculiarity of a particular card rather than to the design drawn upon it.

III. ANIMALS

The animals used in this study were 11 female white rats all approximately four months old and reared in the Stanford laboratory. They were selected at random from a group which had been observed by Dr. Stone to come to puberty at 50 to 55 days, which is average for the females of this colony on a nutritious diet. The average weight, when started on the problem, was 200 grams.

The rats were fed on a standard Steenbock diet which was moistened by the addition of one part of water (by volume) to two parts of meal. Once a week the food was mixed with cod liver oil instead of water. This diet was further varied by allowing the rats to eat lettuce, carrots and fresh orange pulp and peelings several times a week after they had completed the day's trials. The bottoms of the large metal cages in which the rats were kept while not in the dark room were made of one half inch hardware cloth and raised above a tray so the animals could not recover the faeces.

Every rat that started the preliminary work was continued until after the test for the concept had been completed, no matter how slow or inaccurate its record might be. So far as economy of the experimenter's time was concerned, it would have been much better to have started with a larger group of animals and continued only those which showed rapid adaptation to the first problem. However this would have produced data which might

not have been representative of the normal population, and would have lessened the value of any conclusions we might be able to draw.

Because of the time required by a study of this kind it is impossible to use large numbers of animals and subject the data to rigid statistical analysis; but we feel that an *intensive* study of a smaller group will provide a perfectly reliable picture of the rats' ability to make such adjustments.

Since there is no clear cut evidence that the female white rat is superior to the male in the formation of visual habits, the conclusions drawn from these data should not be affected by sex differences.

IV. TECHNIQUE

The general rule which we have attempted to follow in the conduct of this study is to work from the simple to the complex. To this end the rats were started in very simple situations. As soon as a successful reaction had been established, they were introduced to a slightly different set up, but one which made use of the same type of reaction. In this manner we progressed from a specific reaction to an equilateral triangle with apex up, to the choice of cards on which small geometrical designs were arranged in space so as to possess the "quality of triangularity" although no actual triangle was present.

Preliminary training

The rats were placed on the jumping platform with both holes of the apparatus open. The platform was moved close enough that the rats could step through the holes to the food. The distance was increased as rapidly as the rats would allow until they were jumping through the open holes from 25 cm. This took about 50 trials per rat. Then one of the holes was blocked off with a black card and each rat given 20 more trials in jumping to the open hole (the right-left position of this hole was varied in a chance manner). The rats were then given 30 trials where the hole which was formerly open now had a large white triangle in it, and the rats were required to jump to it in preference to the

black card. This they would not do at first and the platform had to be moved closer so that they could push against the cards. After 30 trials during which the position of the large triangle was varied in a chance manner and the platform gradually moved away from the cards, we started the rats on the problem of discriminating a triangle from a circle of equal area. The data contained in table 2 start at this point.

Incentives

During the preliminary training we endeavored to reduce the body weight to 75 per cent of the normal (the method used in the Stanford Laboratory to secure uniformly high motivation on maze problems) and keep it constant thereafter. But where the experimental period extends over several months and the rats are constantly required to adapt to new problems of increasing complexity, we found evidence of "emotional blocks" which were strong enough to invalidate such motivation. As a result we abandoned this policy and kept the animals reduced to the state at which they would jump most quickly. The necessary starvation was found to vary with individual rats and with the difficulty of the problem.

All of the rats were fed on the apparatus and, with the exception of those which at some time during the experiment were so undernourished as to require extra food, only after correct jumps. Thus in a day's trials where but five of ten jumps were correct, the rat would be allowed to eat five different times. If none were correct, the rat would get no food that day, but would be allowed to eat a little longer after making correct jumps on the succeeding day.

When deprivation of food was not enough of a motivating factor to make the rats jump, we removed the water from the living cages and made the food mixture a little wetter. The addition of thirst to the hunger drive usually brought a jumping response. It is the writer's opinion that prolonged starvation of this kind is detrimental, and that under these conditions food soon loses its value as an incentive.

In certain novel test situations we have had animals remain

on the jumping platform for as long as eight hours without making a single jump. In a few of these cases the body weight was reduced to 50 per cent of that at the start of the experiment without speeding up the rat's behavior. When we at last forced them to jump by whipping, they would run around on the food platform but would not eat at once. These animals had to be given an abundance of rich food in order to build up their physical condition before proceeding to other problems.

This whipping technique is not to be recommended for the following reasons:

- (1) If the rats are hit only while facing a particular figure they may (a) jump to it, or (b) go to the other figure and jump. In the first case they have the pain of being hit followed by food, while in the second case the pain of being whipped is followed by bumping their noses and falling to the apron. Under these conditions the rats might come to interpret the punishment as meaning "jump straight ahead," or "go to the other side and jump" and a visual discrimination is not established in either case.
- (2) If the rats can not use the punishment as a cue for making a correct response, they either jump blindly or crouch on the platform and make no effort to react to the figures.

Series order

The order of presentation of the figures (right-left relationship) was determined by three things. (1) Part of the time a fixed series order in which the standard positive figure appeared an equal number of times on each side in ten runs (very similar to that described in a previous paper 4, p. 109) was used. (2) The second was to present the standard figure on either side with a regular single, double or triple alternation, regardless of the rat's reaction. In a series of ten trials, using the triple alternation, the positive figure would appear three times in succession on one side (left), then three on the right, three more times on the left, and once on the right. Over a number of trials the presentations on either side would tend to be equal. (3) The third method was to present the positive figure on one side and keep

it there until the rat had made either one, two, or three jumps in succession to that side, after which it was changed to the other side and kept there until the same number of successive correct jumps had been made. This was found to be the most effective way to control the formation of position habits. If the rats were able to react correctly above 90 per cent of the time on all three of the above series orders, we are quite safe in saying that they were not reacting correctly because they had learned the order of reversal.

Scoring of trials

After the preliminary training each jump was scored as a trial, and the rats were started with ten trials a day. On the first problem if, at the end of ten minutes, the rat had not jumped from a distance of 20 cm., the jumping platform was gradually moved closer until it either jumped or pushed against one of the cards.

A jump was not counted as correct unless the rat's head was pointed at the positive card (triangle) and it obtained food afterwards. If the rat was successful it was allowed to eat while the cards were being arranged, and was then transferred to the ladder leading to the jumping platform. In case the animal jumped to the negative card (circle) it bumped its nose and eventually fell into the apron without securing any food. This counted as a trial although it was scored as an error.

The following types of activity were scored as errors:

- (1) A direct jump to the negative card.
- (2) A "sideways jump" in which the head and front feet hit the negative card, but the rear feet hit and knocked down the positive card. (This was controlled somewhat by increasing the distance between the holes from 2 to $4\frac{1}{2}$ inches, which made it more difficult for the rat to hit both cards at the same time.)
- (3) Any jump which was too short.
- (4) Jumps in which the rat went straight up in the air and hit the flange at such an angle that it was deflected to the floor.
- (5) Any jump to the right or left of both holes.

V. EXPERIMENTAL SECTION

In previous studies we trained rats to discriminate the difference between equilateral triangles of equal area and brightness in two positions (equilateral triangle with apex up as opposed to apex down). When we then presented the rats with a situation in which they were to react to the similarities inherent in all triangles, they failed.

At that time we said,

Since this experiment has been primarily concerned with the problem of visual acuity, the possession of an abstraction has not received adequate study. In the human being, after repeated presentations of all kinds of three cornered figures, in many sizes and positions, the abstraction is finally built up and a specific reaction, the word "triangle" added to all the figures. It is at least reasonable to give the rat an equal chance before denying it the ability to form such a concept (5, p. 345).

In the present experiment we are not trying to establish a discrimination between different positions of the same triangle, but we are trying to establish a reaction which the rat can use to indicate that it perceives a similarity in all triangular figures, and that these factors are different from those which we associate with square, rectangular and circular figures. To attain this end we have given our rats the following training:

- (1) Each rat was trained to meet a criterion of at least 90 correct jumps out of 100 successive trials (two groups of 50 each) to a white equilateral triangle in a single position.
- (2) The rats were then tested:
 - (a) In situations where the *area* and the *position* of the triangle with reference to edges of the card were varied.
 - (b) To determine the positive or negative character of the discrimination established thus far.
 - (c) To determine whether they could react to the triangle if the brightness relationships were changed.
 - (d) These were followed by a test of the discrimination of the white equilateral triangle in new positions and with strange figures.

- (3) Following these tests the rats were *trained* to react to 24 different positions of the white equilateral triangle in combination with a circle.
- (4) The rats were then tested:
 - (a) By presenting combinations of these various triangle positions and strange figures.
 - (b) In situations in which right angle triangles in eight different positions were substituted for the equilateral triangles.
 - (c) On configurations of small geometrical figures to see whether the rats would react to the triangular configuration.
- (5) The rats were then *trained* to jump to a *black* equilateral triangle in a single position.
- (6) They were then tested on a discrimination of the triangle regardless of its color, position, or place in the total pattern.

In the course of this study these eleven rats were given a total of over 40,000 trials, during which they reacted to 80 different stimulus cards arranged in more than 240 separate combinations. Thus the experience which these rats have had with triangles is assumed to more nearly approximate that of human beings and should provide an answer as to whether or not they may possess the concept.

Experiment I. Discrimination between triangle and circle

The initial discrimination of this study is between a white equilateral triangle, apex up, and a white circle of equal area.

Recognizing that there is probably no such thing as "an average rat," group averages will be used merely to indicate general trends and individual records will be used whenever possible. However, there seems to be no question but that a group accuracy of 85 per cent or higher is sufficient to prove that white rats can make a particular response, and that the individuals with lower scores would eventually make the same responses, but merely require a longer training period. The higher the accuracy on the original problem, the more reliable the results on later modifications should be.

This point is clearly illustrated by a reference to one of our own earlier studies. In table 1 (5, p. 335) the group accuracy was 86.4 per cent in the 650th trial. Since the amount of time we could spend in training the rats was limited to five months, and since the group accuracy had met the arbitrarily established standard of 85 per cent, we immediately set *all* of the rats to

TABLE 2

Initial discrimination between triangle and circle

The standard positive figure, the one toward which the rat was to jump in order to get food, is listed under the column headed "positive" (See table 1 for the description of the cards); the test for the discrimination was an individual accuracy of 90 correct jumps out of 100; asterisks indicate the point at which each rat met this standard.

	CA:	RDS		PER CENT OF TIME POSITIVE CARD WAS CHOSEN												
TRIAL	Posi- tive	Nega- tive	1	2	3	4	5	6	7	8	9	10	11	AGE		
50	1	27	52	50	54	44	52	50	56	46	52	52	54	51		
100			34	16	16	14	14	24	20	18	16	18	16	19		
150			46	36	50	18	6	76	34	10	40	18	34	33		
200			36	78	60	60	26	90	30	38	62	56	62	54		
250			28	58	72	44	48	90*	30	60	88	78	68	60		
300			32	66	80	84	68	96	58	78	98*	86	76	75		
350			52	80	84	82	72	94	58	78	90	92	74	78		
400			60	86	76	74	70	100	54	86	98	96*	70	79		
450			72	94*	98	84	68	100	74	100*	98	98	72	87		
500			70	92	96*	90	78	100	68	98	100	92	68	87		
550			80	100	96	92*	76	100	84	100	98	100	86	92		
600			88				62		88				94*			
650			94*				90		96*							
700							86									
750							44									
800							94									
850							94*									

work on the next problem. That this was not advisable is indicated by an inspection of the individual records which show:
(1) Only three rats had maintained an accuracy of 90 per cent in 100 successive trials; (2) two other rats had made an increase of better than 20 per cent in the last 50 trials to have an accuracy of 90 per cent, but both of these, as well as all of the others, had

accuracies of less than 85 per cent for 100 successive trials; (3) four of the ten rats had accuracies of less than 80 per cent. Obviously these individual rats had not perfected the *first* discrimination and could not be expected to contribute any positive results towards the future discriminations. If the group scores on the new problems were to meet the standard, it is evident that certain individual scores would have to exceed it considerably. This does not mean that the group average of 85 per cent is to be construed as of little value in describing certain behavior, but what we do want to point out is that had each individual animal been required to meet the 85 per cent standard, these later descriptions would have been much more convincing.

With the time restriction removed in the present study, we set the minimum individual accuracy on the original training problem at 90 correct choices out of 100 successive trials, and attempted to hold to a group accuracy of 90 per cent or better in the remaining tests.

The data contained in table 2 may be summarized as follows:

- (1) The group average was 92 per cent correct after 550 individual trials.
- (2) The order in which the rats met the standard of 90 correct jumps in 100 trials and the overlearning is as follows:

RANK	NUMBER OF RAT	TRIALS TO LEARN	OVERLEARNING
1	6	250	300
2	9	300	250
3	10	400	150
4	8	450	100
5	2	450	100
6	3	500	50
7	4	550	
8	11	600	
9	7	650	
10	1	650	
11	5	850	

- (3) The average number of trials required to meet the criterion is 513.6, only 13.6 above the median of 500.
- (4) The drop from 51 per cent in the first 50 trials to 19 per cent

in the second 50 trials is attributed to a change in the method of reversing the figures which penalizes position habits.

(5) The record of rat 5 is unique in that after apparently having learned the discrimination in the 650th to 700th trials (86 correct jumps out of 100) the next 50 jumps were only 44 per cent accurate. The succeeding 100 trials produced a response of 94 per cent accuracy. This very sudden reversal of the reaction is similar to that of one other rat (No. 6) which made an increase of 50 per cent accuracy (24 to 76 per cent) in 50 trials and was accurate from that point on.

Although this initial discrimination took much longer (more repetitions) to establish than we had been led to expect from Lashley's report (12), there was still a considerable saving with this apparatus and technique over any that we have previously used. This was reflected not only in the fewer trials, but in the higher accuracy obtained in that period. The running types of apparatus were superior only in that they took less time per trial run.

It will be recalled that Lashley used pigmented animals in his first study (12) and that in the third one of the series he found, "The threshold of pigmented animals for objects 20 cm. distant from the eye is below 52' and above 26'. The threshold of albinos is from 2 to 4 times higher" (13, p. 484). He also reports that "of the patterns tested F, B and D seem to present the greatest difficulties to the animals" (12, p. 457). The fact that all of our rats are albinos and that we have used the triangle and circle (the most difficult pattern for Lashley's pigmented rats) may account for the difference in our scores. The fact that we usually had the jumping stand about 5 cm. closer to the figures that were to be discriminated than Lashley may have compensated in part for the inferiority of the albinos' vision.

Experiment II. Discrimination between figures of unequal area

Although all of the rats had perfected a discrimination between the equilateral triangle and the circle, we did not know which of several features the rats depended upon for their discrimination. There are several possibilities which might provide the cue for a discrimination and the rats still not be reacting to factors inherent in the organization of the triangle.

(1) Even though the two figures are of equal area, this does not mean that their retinal extensions are the same. Each side of the triangle is 8 cm. long, whereas the diameter of the circle of corresponding area is only 5.9 cm. If a rat's visual reaction is similar to the peripheral vision of man, then this discrimination might be made on the basis of retinal extension, even though the total areas are equal.

Collier's data may throw some light upon the point. He equated seven geometrical figures to four degrees as greatest distance between any two points. This of course gave unequal areas, but he reports, "Area does not seem to be of great importance in determining the range over which a figure can be identified. The parallelogram has less area than the square, but is practically on a par with the square. The circle, which can be said to have the largest area of the seven forms, must be rated fifth in this group of forms." And again, "According to the extent of the field in which the figures may be correctly identified, the forms may be ranged in order from least to greatest as follows: octagon, hexagon, circle, parallelogram, square, isosceles triangle, equilateral triangle" (3, p. 289).

In the present study where the areas were equal, the triangle would have a larger retinal extension, and on the basis of Collier's results, should be relatively easier to discriminate than the circle. But in the earlier studies (5, 6 and 12) where the retinal extension was the same and the triangles differed only in their position in space, we should expect to find a much harder discrimination. As a matter of fact, Lashley's results are just the opposite.

(2) The greater retinal extension of the triangle might be interpreted by the rat as a pure size difference, and it might learn to react to the triangle as a *larger area* although actually the areas are equal.

TABLE 3

Discrimination between triangles and circles of varying areas

	CA	RDS		P	ER CEN	T OF	TIME PO	SITIVE	CARD '	WAS CH	OSEN			AVER-
TRIAL	Posi- tive	Nega- tive	1	2	3	4	5	6	7	8	9	10	11	AGE
10	1	28	90	100	90	60	100	100	70	100	100	100	90	91
20			100	90	100	50	100	90	80	100	100	100	90	91
30			90	100	100	100	100	100	100	100	100	100	90	98
4 0			100	100	100	100	100	100	90	100	100	100	100	99
50	1	27	100	100	100	100	100	100	90	100	100	100	100	99
60	1	29	100	100	90	100	100	100	80	100	100	100	100	97
70			100	100	100	100	100	100	100	100	100	100	100	100
80			100	100	100	100	100	100	100	100	100	100	100	100
90			100	100	100	100	100	100	100	100	100	100	100	100
100	1	27	100	100	100	100	100	100	100	100	100	100	90	99
110	25	27	100	100	100	100	100	100	100	100	100	100	100	100
120			100	100	100	100	100	100	90	100	100	100	90	98
130			100	100	100	100	100	100	100	100	100	100	100	100
140			100	100	100	100	100	100	100	100	100	100	90	99
150	1	27	100	100	100	100	100	100	90	100	100	100	90	98
160	26	27	80	100	70	100	90	100	80	100	100	100	80	91
170			100	100	80	100	100	100	80	100	100	100	100	96
180			100	100	80	90	100	100	90	90	100	100	90	94
190			100	100	100	100	100	100	100	100	100	100	100	100
200	1	27	100	100	100	100	100	100	100	100	100	100	100	100
			Tota	l per	cent	corre	ect on	all co	ombi	nation	ıs			
			98	99.5	95	95	99.5	99.5	92	99.5	100	100	95	97.5

(3) With the centers of the two figures coincident with the center of the card, the rats might still react correctly to the triangle because the absolute distance between the apex of the triangle and the top of the card was smaller than that between the circle and the top of the card. Or, they might learn to go to the triangle because as a whole it seemed to be higher in the visual field.

In order to test these possibilities the rats were run on combinations of figures of unequal areas. A summary of the data contained in table 3 reveals:

- (1) The lowest individual accuracy was 92 per cent (rat 7), while two rats (9 and 10) had perfect records for the 200 trials.
- (2) The accuracy of the group reaction to these figures was never below 91 per cent, indicating that these rats were responding to the shape and not to the size of the figures.
- (3) Those rats which had learned the original problem in less than the median number of trials (consequently having the most overlearning) were also superior when reacting to varying sizes of these figures. None of these were below 99.5 per cent accuracy.
- (4) It is to be noted that the highest accuracy was obtained when the area of the positive figure was twice that of the negative figure, and that the relative, rather than the absolute areas, seem to be the important factor. Conversely, the lowest accuracy was recorded when the relative area of the negative figure was twice that of the positive.

This might be stated in another way. The highest accuracies were obtained with combinations of figures in which the retinal extension of the positive figure was greater than that of the negative figure (length of any side of the triangle was greater than the diameter of the circle exposed with it). Conversely, the lowest accuracy (91 per cent) was recorded when the diameter of the circles was slightly larger than the side of the triangle exposed with it.

These data would seem to indicate that these rats were not reacting solely to any one of the features previously listed, but that they were responding primarily to something (as yet undetermined) within the figures themselves. The features within the figures which the rat might use as a basis for the discrimination are as follows:

- (1) The apices of the triangle, although the farthest away, are also equi-distant from the center, while in the circle all of the points on the circumference are equi-distant. This may lead to a recognition of the numerical relationship of "threeness" as being present in the triangle and not present in the circle.
- (2) The balance (center of gravity) of the triangle with the apex up is lower than that of the circle.
- (3) One of the sides of a triangle may be parallel to an established system of coördinates, while the circumference of the circle is not.
- (4) The kinesthetic stimuli which come as the result of the rats looking at the outline of the two figures (movements of the eye or neck muscles) might furnish a differential cue. This possibility may not be as remote as it seems at first, for any one who has seen rats working on the jumping apparatus is struck with their very evident comparison of the two areas.

Experiment III. Positive vs. negative reaction

By this time certain peculiarities in the behavior of the rats on the jumping apparatus were apparent. We have demonstrated in an earlier study (5 and 6) that when the running type of apparatus was used, the rats formed habits of going down one side and made their discrimination by looking at the nearest figure, neglecting the other member of the combination. Thus if the rat ran down the right side of the apparatus and the positive triangle was there, the rat would go under it without looking to the left at the circle; if it encountered the negative circle on the right side, the rat would run on over to the left and go under the figure there. This behavior persisted when only one member of the combination was exposed which led to the conclusion that this response was not only an approach or positive reaction to the triangle, but it was equally an avoiding reaction to the circle.

In order to see whether the nature of the response on the "jumping" apparatus was similar to that obtained on the "running" type, each of these 11 rats was given 200 trials on combina-

tions of the standard triangle and the blank card, and the standard circle and a blank card.

TABLE 4

Test of the positive or negative character of the discrimination

With combination 1 and 30 the rat was required to jump to No. 1 in order to get food; with 30 and 27 the rat was to jump to No. 30, the same card it had avoided in the previous combination. In the last 100 trials where the choice was optional, the rat would get food by jumping at either card of the combination.

	CA	RDS			PE	R CEN	TOFT	IME P	ositiv	E CAR	D WAS	CHOS:	EN		
TRIAL	Positive	Negative	TIMES	1	2	3	4	5	6	7	8	9	10	11	AVER
50	1 30	30 27	25 25	100 48	100	100	96 8	100 24	100 20	100 36	100 36	100 4	100 28	96 40	99
			Total	74	50	50	52	62	60	68	68	52	64	68	61
100	1 30	30 27	10 40	100 34	100	100	100	100 58		100 25	100 75	100	100 68	100 78	100 38
			Total	4 6	20	22	32	66	68	40	80	22	74	82	50
150	1 30	30 27	10 40	100 28	100 10	100 18	70 80	100 100	50 100	100 20	70 100	80 30	50 100	40 88	77 61
			Total	42	28	34	7 8	100	90	30	94	38	90	78	77
200	1 30	30 27	25 25	96 36	100	100 32	44 100	92 100	80 100	92 36	96 84	76 100	52 100	40 92	79 72
			Total	66	54	66	72	96	90	64	90	88	76	66	76
250	38 37	30 30	25 25	48 48	92 48	100	40 44	72 0	96 0	68 48	88	4 0	88	16 0	65 25
300	38 37	30 30	25 25	48 52	76 52	100 56	48 52	92 4	88	52 52	88	0	88	0 4	62 25

Summarizing the data on this point in table 4 (first 200 trials) we find:

(1) The first 25 trials with the triangle and blank gave a group response to the triangle which was accurate 99 per cent of the time. For the first 25 trials, the group response

to the blank in the combination of blank and circle was correct only 22 per cent of the time.

- (2) After 100 additional trials (80 of which were with the blank and circle) we find:
 - (a) The accuracy of the group response to the triangle and blank has decreased 20 per cent (99 to 79 per cent), but the response to the blank and circle has increased 50 per cent (22 to 72 per cent).
 - (b) Rats 1, 2, 3, 5, 7 and 8 still reacted positively above 90 per cent of the time to the triangle.
 - (c) Rats 4, 5, 6, 9, 10 and 11 had changed their response to the blank and circle so that they now jumped above 90 per cent of the time to the blank.

In the case of these rats, we have no evidence that they have learned to avoid the circle when it is presented with a blank card. But what probably has happened is that they have learned to react positively to the blank when it is placed in combination with a circle. This interpretation is consistent with data contained in the remainder of this paper.

- (d) Rats 1, 2, 3 and 7 continued to jump to the figures regardless of their shape.
- (e) Only rats 5, 6, 8 and 9 were able, in the time given, to master a situation which demanded a jump to the triangle when exposed with a blank, and to the blank when it was presented in combination with the circle.

Thus these rats have demonstrated that their reaction is determined by the total pattern rather than by just one of the cards, although they react positively to but one. In the triangle-blank situation we have two cards which are both positive in other combinations, and the circle-blank combination contains cards which are both negative. It is impossible for the rats to make a successful response to one card without first knowing what design is on the other one.

(3) These data (first 200 trials) would seem to indicate that the discrimination between the triangle and the circle is the result of a positive reaction to the standard triangle, and not an avoiding or negative reaction to the standard circle.

In these combinations where we were exposing both the positive and the negative figure with a black card, we found evidence of a new type of position habit. Instead of jumping always to the right or left hole of the apparatus, their reactions took on this form. (1) Always jump to the right of the blank card, circle or triangle. (2) Always jump to the left of the blank card, circle or triangle. (3) Or some combination of the above which would demand a right or left jump depending upon the hole in which one of the cards was shown.

With some of these combinations we had the very interesting case of rats jumping to the right or left of both holes and hitting the solid black wood screen. These were not just chance reactions, but the rats seemed to be trying first one method and then another in an attempt to find a successful reaction to the situation. It would indicate that they did not understand the problem or know what they were expected to do, for as soon as their comprehension of "what the whole thing was about" was perfected, they would need to use only previously established behavior patterns to make perfect scores.

Each of the rats was then given 100 trials with cards on which the standard circle with a triangle circumscribed about it (38) and the standard triangle with a circle circumscribed about it (37) were placed in combination with the blank card (30). The important features of the last 100 trials of table 4 are:

- (1) In every case where a significant difference exists (Rats 2, 3, 5, 6, 8 and 10), it is in the direction which would indicate that the rats were reacting positively to the *outer* white triangle.
- (2) Rats 9 and 11 jumped consistently to the blank.
- (3) Rats 1, 4 and 7 developed position habits as soon as the choice was optional.

The data contained in table 4 would seem to indicate that the

avoiding reaction to the negative figure which was found with the running apparatus is almost totally lacking when the jumping apparatus is used. Since the essential nature of the discrimination is not the same for the two types of apparatus, it is questionable whether the results secured with one should be compared with those obtained on the other.

Experiment IV. Reaction to new brightness relationships

According to the principles of Gestalt Psychology, if rats have previously been trained to discriminate between certain simple figures, then we should expect them to react to the outer or most inclusive figures of the same shape in a more complex stimulus pattern. Borovski (1 and 2) says that color (black and white) assumes different stimulus values when combined with other qualities and that the rats learn to choose black or white and can discriminate size and form, but cannot react successfully to combinations of these. Now then if we should put these two statements together, the conclusion that we might draw is that rats will react to the outermost figure of a stimulus pattern, provided that they have already been trained to choose that particular color. The data contained in the last 100 trials of table 4 support such a statement, but it is more thoroughly tested in this experiment.

Where it is necessary to allow the rats to get food by a jump at either card, and this procedure is extended over a long period, some of the animals set up position habits. Under these conditions, the first ten trials for each rat probably give the best indication of what it was reacting to.

The data contained in table 5 may be summarized as follows:

- (1) As soon as the two cards (38 and 37) which had previously been exposed only with the blank were shown together, the rats reacted positively to the outer white triangle with a group average of better than 90 per cent. (The records of rats 1, 4 and 7 were lowered because of the influence of position habits which were held over from the previous problem.)
- (2) There is no evidence of a group discrimination between the next four combinations of figures, all of which were pre-

sented on white cards (trials 70 to 130). This meant that the outer white figures, the ones to which the animals had been responding previously, were now two white

TABLE 5
Reaction to figures with new brightness relationships

This is a continuation of the last 100 trials of table 4. With the exception of the 160th and the 240th trials, where the rats were blocked from food when they jumped to cards No. 44 and No. 36 respectively, the animals obtained food by a jump at either card. Trials 210 to 240 were made with an all white apparatus.

	CAI	RDS		Pl	ER CENT	OF TIM	E POSIT	IVE CA	ARD W.	AS CH	SEN			AVER-
TRIAL	Posi- tive	Nega- tive	1	2	3	4	5	6	7	8	9	10	11	AGE
10	38	37	50	90	100	70	90	100	80	100	100	100	100	89
20			50	100	100	80	100	100	100	100	100	100	90	93
30			50	100	100	80	100	100	100	100	100	100	100	94
40			60	100	100	100	100	100	100	100	100	100	100	96
50			100	100	100	90	100	100	100	100	100	100	100	99
60			90	90	100	100	100	100	100	100	100	100	100	98
70	41	39	50	50	50	70	10	50	40	60	50	4 0	70	49
80			50	50	50	40	20	50	70	60	50	5 0	60	50
90			50	50	50	50	50	50	50	40	50	30	40	46
100			50	50	50	30	40	50	4 0	80	20	60	50	49
110	41	40	50	50	50	50	50	50	30	50	60	50	50	49
120	42	39	50	50	50	40	50	50	60	50	40	50	40	48
130	32	36	50	50	50	50	40	50	60	40	40	50	40	47
140	43	44	50	50	50	80	100	80	100	100	70	80	60	74
150		` `	50	70	50	100	100	100	100	100	90	100	90	86
160			90	90	80	90	100	100	100	100	100	100	100	95
170	1	32	100	80	60	40	60	60	20	10	100	100	40	61
180			100	60	30	50	60	100	40	10	100	100	40	63
190	1	27	100	80	90	100	100	100	90	90	100	100	80	94
200			100	90	100	100	100	100	100	100	100	100	90	98
210			50	50	50	50	60	50	50	50	70	50	50	53
220			50	50	50	50	50	50	50	50	80	50	50	53
2 30	32	36	50	50	50	50	60	50	50	50	100	50	50	55
240			60	50	50	70	60	50	4 0	4 0	80	60	40	54
25 0	1	27	100	100	100	90	100	100	100	100	100	100	100	99

squares of equal area and similarly located. Rats 1, 2, 3 and 6 established perfect position habits, and rat 5 (70 and 80th trials) was the only individual to give evidence of a discrimination. In this particular case it

was jumping to the standard white triangle enclosed in a black circle, which was in turn surrounded by a large white square.

- (3) The records of the 140 and 150th trials give evidence of a discrimination which was a positive reaction to the outer white triangle in this very complicated pattern (cards 43 and 44).
- (4) Presentation of a white triangle on a black card in combination with a black triangle on a white card gave no definite group discrimination. Rats 1, 6, 9 and 10 jumped to the white triangle but rat 8 jumped to the black triangle. The others reverted to position habits. We can not dismiss the possibility that the rats with the position habits might have used that mode of reaction because they saw two equilateral triangles of equal area and in similar positions. Since they had received no training that would tell them which of two positive equilateral triangles to jump to, they fell back upon position habits and were successful so far as getting food was concerned.
- (5) The white triangle and white circle (cards 1 and 27) were immediately discriminated with an accuracy of 94 per cent (190th trial).
- (6) After substitution of an all white apparatus for the black one, but still using cards 1 and 27, there was only chance discrimination by the group of rats. In this case the outer figures became two black squares of equal area and similarly placed. The use of black figures on white cards (32 and 36) produced no change in the accuracy of the response. Only one rat (No. 9) gave evidence of ability to make the discrimination under these novel conditions.
- (7) A change to the black apparatus with white figures (cards 1 and 27) was followed by a group discrimination of 99 per cent accuracy.

In spite of the rats' tendency to revert to position habits when presented with difficult new stimulus patterns (the choice remaining optional) and the absence of practice on the new combinations, we find: (a) that rat 5 reacted to the *inner white figure*, (b) rat 9 reacted to the *inner black figure*, (c) and that all of the rats but No. 9 formed perfect position habits when they could not differentiate between the *outer black figures*. All of these are exceptions to the formulation which we expressed in the introduction to this experiment.

Experiment V. Reaction to new positions of the triangle and strange figures

After having trained the rats to jump to a white triangle (apex up) of a certain area, our first test for an abstraction was made in experiment II where the rats were to jump to white triangles of various sizes. The second test demanded a jump to a black triangle instead of the white to which they had been trained. The third test, to be made in this experiment, required the rats to jump to white equilateral triangles in new positions. In order to nullify the possibility of the rats making a jump to the triangles solely because they were avoiding the circle, these new triangles were exposed with strange figures.

The data contained in table 6 may be summarized in the following manner:

- (1) Whenever the triangle (1) to which the animals had been trained was exposed with other figures (cards 45, 46 and 47), the rats chose the triangle with an accuracy of 94 per cent, indicating that a positive reaction had been established to it.
- (2) Whenever the circle (27) to which the rats were accustomed was exposed with strange figures (7, 18 and 24), the accuracy of the discrimination drops to that expected by chance (48.5 per cent), indicating that a negative or avoiding reaction to the circle had not been established.
- (3) The discrimination of triangles in certain new positions when exposed with a rectangle, cross and square is lower than that expected by chance (28 per cent), which suggests the following possibilities:
 - (a) The rats can see a difference between these two new figures.

- (b) They recognize that the new position of the triangle is changed from the one on which they were originally trained.
- (c) Although they can visually note these differences, the rats do not know "what to do about it," or how to react in a successful manner. Additional training on these combinations does not increase the acuity of the visual reaction, but provides the

TABLE 6

Discrimination between new positions of the equilateral triangle and strange figures

	CA	RDS		P	ER CENT	OF TIM	ie posi	rive CA	ARD W	AS CH	OSEN			AVER-
TRIAL	Posi- tive	Nega- tive	1	2	3	4	5	6	7	8	9	10	11	AGE
10	7	47	40	10	40	0	10	0	0	0	0	0	0	9
20	18	46	30	10	50	30	30	30	0	30	0	0	20	21
30	1	47	100	70	100	70	100	80	100	90	100	90	100	91
40	1	46	100	90	100	90	100	100	90	90	100	100	90	95
50	7	27	50	30	40	40	60	50	30	60	30	20	50	42
60	18	27	70	40	50	40	50	50	50	100	50	70	70	58
70	24	45	60	50	50	50	30	50	50	50	50	60	100	55
80	1	45	90	100	100	70	100	100	100	100	100	90	100	95
90	24	27	70	50	50	50	50	50	60	50	40	10	20	45
100	1	27	100	80	90	100	90	100	100	100	100	100	80	94
110	1	47	100	90	90	80	100	100	80	90	100	90	100	93
120	3	47	90	100	80	90	70	70	80	80	90	80	80	83
130			80	100	100	90	100	90	70	80	100	90	80	89
140			90	90	100	90	100	100	100	80	100	100	80	93
150	5	47	70	40	20	30	40	50	30	20	40	30	40	37

animal with a successful mode or responding to the already perceived visual differences.

- (d) To the rat, these new figures may appear more like the triangle on which they were originally trained than do the new positions of the same triangle.
- (e) The rats are not able to successfully react to the quality of triangularity (triangularity per se) after experience with but one type of triangle in a single position.
- (4) The position of the triangle may be changed, within certain small limits, without destroying the positive reaction to it.

The failure of these rats to jump to the triangle in its new positions may be somewhat analogous to the situation which James relates concerning a father who "wishes to show some guests the progress of his rather dull child in kindergarten instruction. Holding the knife upright on the table, he says, 'What do you call that, my boy?' 'I calls it a knife, I does,' is the sturdy reply from which the child cannot be induced to swerve by any alteration in the form of the question, until the father, recollecting that in the kindergarten a pencil was used and not a knife, draws a long one from his pocket, holds it in the same way, and then gets the wished for answer, 'I calls it vertical.' All the concomitants of the kindergarten experience had to recombine their effect before the word 'vertical' could be reawakened' (11, pp. 568–69).

Experiment VI. Discrimination between new positions of the triangle and the circle

Obviously the child referred to by James must have many experiences with other objects (pens, rulers, trees, etc.) in a vertical position before he will be able to make the desired language response "vertical" as an indicator of a recognized relationship. This is equally true with our rats, and the next 1050 trials are designed to give them experiences with a white equilateral triangle in many different positions.

A question immediately apparent is, "What is the most efficient method for presenting the rats with these experiences?" Hull has studied the relative efficiency of the simple-to-complex as opposed to the complex-to-simple order and arrived at the conclusion that the first method had an advantage, due principally to the great amount of time spent on the simpler cases. But when the time factor is eliminated, "the advantage of the simple-to-complex method is completely eliminated also. This fact, together with the shape of the two curves throughout the evolutionary process, indicates that the simpler characters are much more efficient in the evolution of concepts than complex ones. There appears to be no advantage in the simple-to-complex order merely as such (9, p. 84)."

Since each of our rats had already had from 1450 to 1750 trials

TABLE 7
Reaction to gradual rotation of the triangle

	CA	RDS	PER CENT OF TIME POSITIVE CARD WAS CHOSEN											
TRIAL	Posi- tive	Nega- tive	1	2	3	4	5	6	7	8	9	10	11	AGE
10	1	27	100	100	100	90	100	100	100	100	100	100	100	99
20	2	27	100	100	100	90	100	100	100	100	100	100	100	99
30	3	27	100	100	100	100	100	100	100	90	100	100	90	98
40	4	27	100	90	100	100	90	100	100	100	100	100	90	97
50	5	27	90	90	100	100	100	100	90	90	100	100	100	96
60	6	27	100	100	90	100	90	100	100	90	100	100	90	.96
70	7	27	80	80	90	100	90	100	80	80	50	40	80	79
80			70	50	80	70	90	100	80	100	90	90	70	81
90			80	100	90	90	100	90	60	80	100	80	70	85
100			80	90	100	70	100	100	90	90	100	90	80	90
110			80	90	100	80	100	100	80	90	100	80	90	90
120			100	90	100	100	100	100	100	90	100	100	90	97
130	8	27	80	60	70	80	80	90	80	80	60	60	80	74
140			70	80	80	70	90	100	70	90	60	50	70	75
150			60	90	80	90	90	70	80	90	60	100	80	81
160			90	90	100	90	100	90	70	90	90	90	80	89
170			90	100	90	90	90	100	80	80	80	80	90	88
180			100	90	90	90	100	90	100	100	90	90	100	94
190	9	27	100	90	90	100	100	90	80	90	100	90	90	93
200	10	27	80	70	100	70	100	80	60	70	80	30	30	70
210			100	90	90	90	100	80	90	90	70	70	70	85
220			100	100	100	90	90	100	90	90	90	90	100	94
230	11	27	80	80	80	70	80	40	60	60	100	60	40	68
240			100	90	50	80	90	50	80	90	70	80	90	79
250			100	100	70	80	80	80	70	80	80	80	100	84
260	11	27	100	80	80	90	90	80	60	90	90	60	70	81
270			100	100	80	100	90	90	80	80	80	80	90	88
280			100	80	100	70	70	70	70	70	70	80	90	79
290			60	50	90	80	70	50	50	60	100	60	60	66
300			30	60	100	70	80	70	70	80	100	70	70	73
310	1	27	100	100	100	100	100	100	100	100	100	100	90	99
320	24	27	40	0	90	80	70	30	50	20	60	50	20	46
330	3	27	100	80	100	80	100	100	80	100	100	100	70	91
340			100	100	100	90	100	100	100	100	100	100	100	99
350	14	27	100	90	100	80	100	100	100	100	100	100	80	95
360	16	27	90	100	100	90	100	80	100	100	90	90	80	92
370	5	27	100	90	100	90	100	100	100	80	100	100	90	95
380	7	27	100	100	100	70	100	90	100	100	100	100	80	94
390	18	27	60	50	0	30	70	40	60	80	50	10	30	44
400			90	60	40	70	100	80	50	80	70	70	70	71

TABLE 7-Concluded

TRIAL	CAI	RDS	PER CENT OF TIME POSITIVE CARD WAS CHOSEN											AVER-
TRIAL	Posi- tive	Nega- tive	1	2	3	4	5	6	7	8	9	10	11	AGE
410			60	60	40	30	60	80	80	70	60	20	20	53
420			80	60	50	70	60	80	70	90	70	50	90	70
430	7	27	70	90	100	80	100	100	80	80	100	90	70	87
440	18	27	40	50	50	70	30	50	50	100	20	50	40	50
450	7	27	90	90	100	70	100	80	80	90	90	80	80	86
460			80	70	100	50	100	100	100	80	90	100	50	84
470			100	90	100	80	100	100	90	80	100	70	60	88
480			70	80	100	70	90	50	30	80	90	40	80	71
490			80	70	100	60	90	70	90	60	100	90	60	79
500	1	27	100	100	100	90	100	100	90	100	100	100	80	96

(exclusive of the preliminary training) on the simplest situations, and they had demonstrated in table 6 that they could make a positive transfer when the triangles were rotated but a few degrees, we decided to continue the simple-to-complex method. In view of the fact that the rats had demonstrated that their discrimination on the jumping apparatus was almost solely due to a reaction to the standard positive triangle, and that the second member of the combination did not make much difference, we continued to present a circle of equal area with the new triangle positions.

The results of the first 500 trials are presented in table 7 and may be summarized as follows:

- (1) By reducing the interval from ten degrees in table 6 to five degrees, the rats were able to immediately discriminate with group accuracy of 96 per cent or better all of the triangles up to and including the 25 degree rotation to the left (cards 1 to 6).
- (2) Sixty trials with the 30 degree rotation to the left (card 7) were required before a group accuracy of more than 90 per cent was obtained.
- (3) Sixty additional trials were needed before the 35 degree rotation (card 8) was learned.
- (4) There was immediate discrimination of the next 5 degree rotation (card 9), and only 30 more trials were necessary for the 45 degree rotation (card 10).

- (5) The 50 degree rotation (card 11) was not learned in 80 trials, and there was considerable variation in accuracy from one run to another. The group accuracy seemed to be diminishing because of "blocks" of some kind. The record of rat 1 is an example. In the 290 and 300th trials its accuracy decreased tremendously although the cards were the same that it had previously responded to perfectly.
- (6) Presentation of the original cards (1 and 27) gave 99 per cent group accuracy (trial 310).
- (7) Inversion of the original triangle (card 24) was followed by chance accuracy.
- (8) By alternating a 10 degree rotation to the left with a 10 degree rotation to the right, we were able to build a discrimination of better than 90 per cent accuracy up to and including the 30 degree rotation to the left. But presentation of the 30 degree rotation to the right gave only a chance discrimination, and after repeated trials on it, the accuracy of the response to the previously established rotations to the left disintegrated.
- (9) In spite of the disintegration of the discrimination of rotated triangles, the original figure was chosen immediately with 96 per cent accuracy
- (10) Had a negative reaction been established solely to the circle, the presentation of rotated triangles should not have affected the accuracy of the response.
- (11) The direction of the rotation seems to be as important as the amount of rotation, in so far as it affects the accuracy of the discrimination.
- (12) "Pushing" the animals, by presenting new triangles (with greater degrees of rotation, or with rotation in the opposite direction) before the rats had thoroughly mastered the earlier stages, results in a disintegration of the accuracy of response to figures which had been learned. This is probably due to an "emotional block" of some kind.

In this portion of the experiment we had assumed that a group

accuracy of 92 per cent or better for 10 trials indicated mastery of the situation, and a triangle in a new position was immediately substituted in place of the old one. That this assumption was probably not well founded is indicated by the number of instances in which the reaction to previously learned situations disintegrated with the introduction of new triangle positions, but the reaction to the original triangle and circle, on which every rat was required to make an individual accuracy of at least 90 correct jumps out of 100 successive trials, was not affected. These results might be explained if we think of the rats as being able to discriminate the new position of the triangle with an accuracy of above 90 per cent for ten trials, but doing so under considerable strain. Immediate insertion of another triangle rotated 5 degrees more, before the reaction to the previous one had been automatized, might lead to confusion and resultant emotional blocks of sufficient intensity to retroactively destroy all the discriminations except those which had been thoroughly mastered.

During these periods we tried various means of motivating the rats (increased hunger and thirst, sometimes resorted to whipping, and varied the distance between the edge of the platform and the figures) in order to speed up the jumping process, but none of them were effective. As the accuracy diminished, so did the speed of the reaction.

It might be well to quote from the daily record to indicate the change in behavior that took place as soon as the original triangle (card 1) was substituted for these rotated triangles. "Many times, on the first trial, the rats would crawl up to the edge of the jumping platform very slowly, look listlessly at the triangle, then all at once seem to recognize the figures, become enthused, running rapidly from one to the other, then jump quickly to the triangle."

This very anthropomorphic description may have some justification in fact. Immediately previous to the introduction of the original triangle, it may have taken more than eight hours to get 10 jumps from each of 11 rats (total of 110 jumps) and the accuracy was low. But the first 10 jumps for the same animals after this triangle was inserted gave accuracies which were always above 90 per cent, and many times the 110 jumps were completed in one and one half hours.

Since we were not successful in building up the discrimination by gradual steps, we next decided to take four widely separated positions of the triangle and keep the rats working on them until we got a group accuracy of better than 90 per cent for 50 trials. This criterion should provide a better basis for assuming that the rats had mastered the situation than the previous one of 92 per cent in 10 trials.

TABLE 8

Discrimination of certain widely separated positions of the triangle

	CARDS			PER CENT OF TIME POSITIVE CARD WAS CHOSEN										
TRIAL	Posi- tive	Nega- tive	1	2	3	4	5	6	7	8	9	10	11	AVER
50	24	27	66	48	78	54	58	50	52	20	70	66	42	55
100			80	54	96	82	72	68	90	56	86	86	56	75
150			98	66	98	86	94	86	98	80	92	96	72	88
200			96	88	100	94	98	94	98	86	98	100	86	94
2 50	7	27	100	94	100	98	100	96	94	98	100	100	84	97
300	18	27	84	92	86	56	92	66	72	70	68	58	68	74
350			92	94	82	90	98	96	92	98	86	72	72	88
400			94	92	92	92	100	92	98	96	98	96	94	95

These data are contained in table 8 and may be summarized as follows:

- (1) After 200 trials with the inverted triangle (card 24),
 - (a) The last 50 trials gave a group accuracy of 94 per cent.
 - (b) Rats 1, 3, 4, 5, 6, 7, 9 and 10 met the criterion of 90 correct jumps out of 100 successive trials.
 - (c) Rats 2, 8 and 11 all made 86 per cent or better in the last 50 trials.
 - (d) The average group accuracy for the last 100 trials was 91 per cent.
- (2) The first 50 trials with the triangle rotated 30 degrees to the left (card 7) gave a group response of 97 per cent accuracy, with rat 11 the only one below 94 per cent (84 per cent).

- (3) After 150 trials with the triangle rotated 30 degrees to the right (card 18),
 - (a) The last 50 trials gave a group accuracy of 95 per cent, with every rat making 92 per cent or better.
 - (b) Rats, 1, 2, 4, 5, 6, 7, 8 and 9 met the criterion of 90 correct jumps out of 100 successive trials.
 - (c) The average group accuracy for the last 100 trials was 91.5 per cent.

TABLE 9

 $Test for the \ effect \ of \ previous \ training \ upon \ the \ discrimination \ of \ intermediate \ degrees$ $of \ rotation$

After the first 50 trials, the number of the positive cards and the order of their exposure in each series of 10 runs is as follows: 60—1 to 10; 70—1, 13 to 21; 80—1, 13 to 21; 90—20 to 24, 12 to 8; 100—20 to 24, 12 to 8; 110—1, 24, 16, 9, 18, 7, 20, 5, 24, 1; 120—14, 11, 22, 3, 17, 8, 19, 6, 13, 12; 130—23, 2, 15, 10, 21, 4, 1, 24, 18, 7; 140—1, 18, 24, 7, 1, 18, 24, 7, 1, 18; 150—18, 18, 7, 7, 1, 1, 24, 24, 18, 18.

	CAI	RDS		PER CENT OF TIME POSITIVE CARD WAS CHOSEN											
TRIAL	Posi- tive	Nega- tive	1	2	3	4	5	6	7	8	9	10	11	AGE	
10	1	27	100	100	100	80	100	100	100	100	90	90	100	96	
20	24	27	100	100	90	100	100	100	100	100	100	100	90	98	
30	18	27	100	90	100	100	90	100	80	90	100	90	70	92	
40	7	27	100	100	100	90	100	90	90	100	90	100	80	94	
50	18	27	100	80	80	90	100	100	100	90	90	90	80	91	
60		27	100	100	100	100	100	100	100	90	90	100	80	96	
70			100	70	90	100	90	100	70	100	90	90	90	90	
80			100	90	80	100	100	100	100	100	90	100	80	94	
90			90	80	90	90	100	90	100	90	100	100	90	93	
100			90	80	70	90	90	80	90	80	100	100	90	87	
110			100	80	90	90	100	100	100	90	100	100	100	95	
120			100	80	100	100	100	100	100	100	100	80	100	96	
130		()	100	100	100	100	100	100	100	100	100	100	90	99	
140			100	90	100	100	100	100	100	100	100	100	100	99	
150			100	80	100	90	100	100	90	90	100	100	100	95	
Tota	al		99	88	93	95	98	97	95	95	96	96	89		

Having established a discrimination of the four principal positions of the equilateral triangle, the next thing was to determine whether the rats could make use of this training so as to discriminate the intervening triangle positions.

These data are contained in table 9 and may be summarized in the following manner:

- (1) It will be noticed that the group accuracy fell below 90 per cent but once (100th trial), and that in this instance the identical cards had been discriminated with an accuracy of 93 per cent in the preceding trial.
- (2) The individual accuracy for the 150 trials during which 24 different positions of the triangle were exposed was below 93 per cent in only two cases; rat 2 was 88 per cent and rat 11 was 89 per cent correct.
- (3) This provided good evidence that these rats would react positively to an 8 cm. equilateral triangle in any position as long as it was exposed with a circle of equal area, both figures being white.

If we analyze the data up to this point with reference to the number of trials taken to acquire a group accuracy of 90 per cent for 50 trials to different positions of the triangle, these significant features come to light.

- (1) The rats needed 580 trials (including preliminary training of 30 trials) to learn the triangle in the first position (card 1).
- (2) The second triangle position (card 24) was learned after 230 presentations.
- (3) After 500 trials with 11 different triangles rotated to the left, 150 of these trials being with card 7, the rats could react correctly to any triangle rotated to the left (cards 2 to 12).
- (4) After 240 trials on three triangles rotated to the right (cards 14, 16 and 18), 220 of which were to card 18, the rats could react correctly to any of the 11 triangles with rotations to the right (cards 13 to 23).

If this is interpreted in terms of the average number of trials necessary to learn a particular triangle position, the results would take this from. The first position requires 580 trials; the second position requires 230 trials; the next 11 positions would require 45 trials apiece; and the remaining 11 positions would require but 21 trials apiece.

Another point that might be implied by the rat's failure to respond positively to the new positions of the triangle upon their first presentation, is that the rat may have some mechanism (either internal or external to the organism) by means of which it judges the figures. Now then if the rat, using this system of coördinates, is trained to react to a figure whose shape and position in space are kept constant for a considerable period, then any displacement of this figure (the shape or internal organization remaining constant) might cause a lowering of the accuracy of the response,—not because the shape and the qualities of the figures are changed, but because its position with respect to the preestablished system of coördinates has been changed. Thus we have no more evidence to prove that the rats do not perceive the figure in its new position as a triangle (with all of the qualities inherent in such designs) than that they do perceive this internal organization, but recognize that it occupies a new place in their system.

What they have learned to react to may be the *position* of a particular triangle rather than the similarities inherent in all triangles. In order to establish this reaction to the similarities in the triangles, it might be necessary to reverse the technique we have used in this study and present as many different positions of the triangle as possible in successive trials from the very beginning of the training period. Given no opportunity to establish a discrimination to a particular position, the rats might be forced to rely upon the more general features common to all triangles, but not to other figures. This should be tested with further experimental work, not only with animals, but with human subjects as well.

Experiment VII. Retest of reaction to new triangle positions and other figures

After having established a discrimination between any position of the white equilateral triangle and a circle of equal area, we wished to determine what the reaction would be when the rats were presented with the same combinations of figures used in table 6. If they had learned the different triangle positions in the last 1050 trials and were reacting positively to them, then the

TABLE 10

Reaction to the same combinations of figures used in table 6, but after training on rotated triangles

A 7 day rest interval was given between the completion of table 9 and the start of table 10.

	CAI	RDS		PER CENT OF TIME POSITIVE CARD WAS CHOSEN											
TRIAL	Posi- tive	Nega- tive	1	2	3	4	5	6	7	8	9	10	11	AVER-	
10	7	47	90	70	90	80	100	100	80	90	90	90	70	86	
20	18	46	50	70	80	90	90	50	70	90	100	90	90	79	
30	1	47	90	80	70	70	80	80	80	90	90	70	70	7 9	
40	1	46	100	90	100	100	90	80	80	100	80	80	80	89	
50	7	27	90	100	100	100	100	100	90	90	100	90	100	96	
60	18	27	80	100	80	100	100	100	100	80	100	100	90	94	
70	24	45	80	80	100	100	90	90	90	90	90	100	70	89	
80	1	45	100	100	100	100	100	100	80	90	100	100	80	95	
90	24	27	90	100	100	100	100	90	90	100	100	100	90	96	
100	5	47	90	80	80	90	100	100	90	80	80	90	90	90	
110	7	47	100	90	90	100	100	90	100	100	100	90	90	95	
120	18	46	90	80	90	90	90	80	90	80	80	100	90.	87	
130	1	47	100	100	100	90	100	90	100	100	100	90	80	95	
140	1	46	100	100	100	100	100	100	90	100	100	90	100	98	

Comparison of data in tables 6 and 10

CAI	RDS	GROUP A	CCURACY,	
Positive	Negative	Table 6	Table 10	
		per cent	per cent	
1	47	93	95	
1 (46	95	98	
1	45	95	95	
7	27	42	96	
7	47	9	95	
18	46	21	87	
18	27	58	94	
24	45	55	89	
24	27	45	96	
5	47	37	90	

introduction of new figures should not affect this response and we would expect the rats to reverse the type of response recorded in table 6.

These data are presented in table 10 and may be summarized in the following manner:

(1) The group accuracy for the first 40 trials on these figures was 84 per cent, while the group accuracy for the last 40 trials (same combination of figures) was 94 per cent, an actual increase of 10 per cent.

In table 6 the reaction to cards 1 and 46, and 1 and 47 was 94 per cent accurate upon their very first presentation; but in the 30 and 40th trials of table 10 the reaction to the same combinations was only 84 per cent correct. Since the scores on the second presentation of the figures in table 10 are probably more representative of the rats' ability, they will be used for further comparisons.

(2) Whenever the triangle to which the rats were originally trained was exposed with other figures, the rats chose the

triangle with an accuracy of 96 per cent.

(3) Exposure of the standard negative circle with the new positions of the triangle was followed by a response which was accurate 95 per cent of the time.

(4) The rats now jump to certain positions of the triangle when exposed with a rectangle, cross and square about 91 per cent of the time.

(5) The discrimination of the triangle rotated 20 degrees to the left and a rectangle was accurate 90 per cent of the time.

(6) For ease in comparison, the pertinent data in tables 6 and 10 are reproduced at the end of table 10. The group response to the triangle in the new combinations upon their first presentation is contained in table 6, and the rats had no further experience with these combinations until they were presented for the second time in table 10.

The very noticeable change in the reaction to combinations of new triangle positions and certain other figures can only be attributed to the building up of a specific positive reaction to the new triangle positions during the last 1050 trials. This reaction was carried over when a square, a certain rectangle and a cross were substituted for the negative circle which had been used during the training period.

Because of the strain apparent by the time the rats had com-

pleted experiment VI, we thought it best to give them an opportunity to recuperate somewhat before continuing the study. It is unfortunate that the rest period intervened at this particular point, for at the end of table 9 the average weight for the rats was 160 grams and there was no question but that they were well motivated. Following the rest period and after five day's trials on table 10 (ten trials a day) the average weight was still 184 grams. By the time the trials contained in this table were completed, the average weight had been reduced to 170 grams. It is my opinion that the 10 per cent higher accuracy for the last 40 trials over the first 40 is to be attributed to the higher motivation.

We found that it was impossible during the remainder of this study to reduce the weight to the previous low figures. Whenever we attempted it the rats would not work, and as a result we allowed the average weight to slowly increase to 189 grams after the final test for the concept had been completed in table 12.

Table 10 presents data on the reaction to only four widely separated positions of the triangle in combination with three relatively strange figures. In table 11 these data are extended to include the reaction to 20 other positions of the triangle and five new figures. In a series of 20 jumps, the first 10 (in order to be correct) must be to a triangle with different degrees of rotation to the left, and the second 10 jumps must be to triangles with different degrees of rotation to the right. This would give a number of unfamiliar patterns in which the rats would have to jump to the triangular figure in order to secure food, and should provide additional evidence concerning the positive character of the discrimination and the rats' ability to react to a wider range of figures.

The data contained in table 11 may be summarized as follows:

- (1) In seven of ten cases the 2–12 card sequence (triangles rotated to the left) was productive of a higher discrimination score than the 13–23 sequence (rotation to the right). In only two cases were the triangles rotated to the right chosen more than those rotated to the left.
- (2) Cards 46, 48, 49 and 50 produced accuracies of less than 90 per cent; No. 49 was the lowest with a group average

- of only 80 per cent accuracy while all of the others were above 85 per cent.
- (3) It is to be noted that the combinations which produced the lowest accuracies were made up of rectangles with measurements corresponding to the base and the altitude of the original triangle. Thus it was most difficult for the

TABLE 11

Reaction to 20 different positions of the equilateral triangle in combination with 9 other figures

Card No. 7 was omitted in the 2-12 sequence (rotation to the left), and No. 18 was omitted in the 13-23 sequence (rotation to the right).

	CARI	os		PE	R CENT	OF TIM	ie pos	ITIVE	CARD	WAS C	HOSEN	r		AVER-
TRIAL	Positive	Nega- tive	1	2	3	4	5	6	7	8	9	10	11	AGE
10	2-12	27	100	100	100	100	100	100	100	90	100	100	100	99
20	13-23		90	80	90	90	90	100	80	100	100	80	80	89
30	2-12	51	100	90	100	100	100	100	100	100	90	100	100	98
40	13-23		100	100	90	100	100	100	100	100	100	100	90	98
50	2-12	45	100	100	100	100	100	90	80	90	100	100	90	95
60	13-23		90	100	80	80	100	90	80	100	100	100	100	93
70	2-12	52	90	100	100	100	90	100	100	80	100	100	100	96
80	13-23		90	90	80	100	100	90	90	80	100	100	80	91
90	2-12	46	80	70	100	100	90	80	90	100	80	90	90	88
100	13-23		90	100	70	80	90	80	90	90	80	70	100	85
110	2-12	49	100	80	100	80	90	70	80	80	70	100	100	86
120	13-23		80	70	90	70	80	70	60	80	70	100	40	74
130	2-12	50	80	80	90	100	90	70	90	80	80	80	80	84
140	13-23		100	100	90	100	80	70	100	70	90	90	80	88
150	2-12	46	100	80	100	90	90	80	80	80	100	80	90	88
160	13-23		100	80	100	80	100	80	90	90	100	80	100	91
170	2-12	47	90	90	100	100	100	90	80	70	100	90	90	91
180	13-23		100	80	90	90	80	80	90	90	100	100	90	90
190	2-12	48	90	90	90	70	100	80	90	80	90	90	80	86
200	13-23		90	80	70	70	70	100	90	80	100	100	80	85

rats to discriminate various positions of an 8 cm. equilateral triangle when they were exposed with a rectangle of equal area whose base was 8 cm. The next most difficult discrimination was between the triangles and a rectangle whose vertical side was equal to the altitude of the original triangle.

The results obtained in trial 110 present something of a contrast to those reported in an earlier study (4). In that study we had given five white rats 1090 trials apiece during which they were to react positively to a white equilateral triangle with the apex up (similar to card 1 of the present study). We had succeeded in getting a group response to this triangle which was 89 per cent accurate (table 4). But when we exposed this triangle with a rectangle whose base and area were equal the accuracy of the response fell off and it required an additional 1350 individual trials before the group accuracy reached 85 per cent.

In the present study, when we presented a rectangle whose base was equal to that of the triangle with ten different positions of the triangle rotated to the left, the group response to the triangle was 86 per cent correct in the first ten trials, or slightly better than in the previous study after 1350 trials on the combination. The second ten trials with the same rectangle but presented with ten triangles rotated to the right, gave a response to the triangle which was accurate only 74 per cent of the time. One animal accounts for nearly half of this decrease.

It is hard to tell what this drop in accuracy between the 110 and 120th trials means. There was a similar decrease just 100 trials earlier when the triangles rotated to the left were chosen with 99 per cent accuracy and those rotated to the right were chosen with 89 per cent accuracy (trials 10 and 20). In both of these instances the time required to make the second ten jumps trebled that required for the first ten.

This 80 per cent accuracy (average for trials 110 and 120) is hard to interpret even when we recall that of the triangles only card 1 had a figure whose 8 cm. base would occupy the same position as the base of the 8 cm. rectangle (both parallel to the same system of coördinates), but this original triangle was not included in the figures exposed with the rectangle.

If we were to assume that the rats had learned to react to the parallel base of the original triangle, then it might be possible that the position of the rectangle in this combination was confusing. That something more than the parallel bases is involved is indicated in the response to another rectangle with a base 1 cm. less (card 47), which gave 90 per cent accuracy.

Had we presented this 8 cm. rectangle again, as we did the square (card 46) when we obtained an increase from 86.5 per cent to 89.5 per cent accuracy, this discrimination might have been raised. With the triangle (card 1) the base was 6.6 cm. from the lower edge of the card; the base of the 6.9 cm. rectangle (card 47) was 6.9 cm. from the lower edge, and the base of the 8 cm. rectangle was 7.2 cm. above the lower edge of the card. In this situation it is evident that the vertical displacement of the base of the figures is not as important as the amount of their horizontal extension, and that any deviation from the horizontal is more important than either.

These data would seem to indicate that the rats, after appropriate training on triangles and a circle, are able to react positively to the triangles regardless of what the other member of the combination might be, but that the discrimination becomes more difficult as the dimensions of the negative figure approach those of the triangle. The horizontal distribution of the figures seems to have more of a bearing upon the discrimination than the vertical distribution.

Experiment VIII. Test for the "concept" of triangularity

In the previous experiments of this study we established a positive reaction to a white equilateral triangle in a particular position, then positive reactions to any position of the equilateral triangle. So far, these data might be explained on the basis that the rats were responding to "identical existential elements" in the various stimulus patterns although we are not in a position to say just what the particular elements are. From the ease with which the rats transferred to various sizes of the white equilateral triangle, the relative position with respect to a system of coördinates remaining constant, we might assume that these elements had something to do with the internal organization of the figures. But when the size of the figures and their internal organization were kept constant and only the relation to a system of coördinates varied, the rats did not transfer at first and the difficulty of the discrimination seemed to bear a relation to the amount of the change.

James says,

When we discriminate an element we may contrast it with the case of its own absence, of its simply not being there, without reference to what is there; or we may also take the latter into account. Let the first sort of discrimination be called existential, the latter differential discrimination. A peculiarity of differential discriminations is that they result in a perception of differences which are felt as greater or less one than the other. Entire groups of differences may be ranged in series. . . . In passing from term to term in any such series we are conscious not only of each step of difference being equal to (or greater or less than) the last, but we are conscious of proceeding in a uniform direction, different from other possible directions. This consciousness of serial increase of differences is one of the fundamental facts of our intellectual life (11, p. 489–90).

According to this we may have demonstrated both existential and differential discrimination in the white rat, but we still do not know whether the discrimination is of mere retinal patterns (unequal stimulation of different parts of the retina), or whether it might not be a discrimination of qualities inherent in the retinal organization.

Since the rats had not yet exhibited the more complex behavior of perceiving "identity in diversity" upon which the highest type of concept formation is supposed to depend, it would be necessary to demonstrate that the rat can perceive identity in diversity and react correctly to qualities inherent in configurations of stimuli with which it had no previous experience before our use of the term "concept" with reference to the behavior of white rats could be extended to include certain implications which have hitherto been reserved entirely to man.

In this test situation it is especially important that no chance position factors operate to influence the rats' choice of the figures. As a result we relied entirely upon single, double and triple alternations in each series of ten trials for our reversal of these figures. These series orders are severe in penalizing position habits (note drop from 51 per cent accuracy in the first 50 trials of table 2 to 19 per cent accuracy in the next 50 trials after this order of reversal was used) and we are relatively sure that these scores are not raised in any degree by chance factors.

Table 12 contains the data which we gathered in an attempt to test the reaction to these complex stimulus patterns and may be summarized as follows:

(1) In the first 40 trials during which 20 different positions of the equilateral triangle were shown in combination with

TABLE 12

Test for the "concept" of triangularity

The rats were required to jump to the card which had the triangle or "triangular configuration" upon it in order to secure food.

	CARI	s		PE	RCENT	OF TIM	E POS	ITIVE	CARD	WAS CI	HOSEN		and the same of th	AVER-
TRIAL	Positive	Nega- tive	1	2	3	4	5	6	7	8	9	10	11	AGE
10	2-12	27	100	100	100	90	100	100	90	80	90	80	90	93
20	13-23	27	100	100	100	100	100	100	100	80	100	100	90	97
30	2-12	27	100	90	100	90	100	100	90	80	100	90	90	94
4 0	13-23	27	100	90	100	100	90	80	100	90	80	90	90	92
50	53-60	27	100	80	90	100	100	100	80	80	100	100	90	93
60	53-60	61	100	100	100	100	100	100	100	100	100	100	100	100
70	64	27	20	10	40	10	70	20	40	60	70	20	10	34
80	65	68	70	50	60	70	70	60	80	80	70	60	90	69
90	65	62	100	70	100	80	100	100	100	90	70	90	90	90
100	64	63	60	80	60	70	80	100	80	60	70	50	80	72
110	64	67	80	70	7 0	80	70	70	80	70	90	90	70	76
120	66	63	60	70	60	4 0	50	60	40	60	60	60	50	55
130	69	63	100	90	100	100	100	100	90	90	80	90	100	95
140	70	62	100	90	90	80	90	90	80	80	100	100	100	91
150	64	63	80	100	100	90	100	100	80	100	80	100	90	93
160	71	74	90	80	90	80	80	60	90	70	80	80	90	81
170	72	73	90	100	90	100	90	80	90	90	90	100	70	90
180	76-77	75	100	90	90	90	100	70	100	100	100	100	80	93
190	64	27	90	100	100	90	100	100	90	90	100	100	80	95
200	78-79	80	100	100	100	90	80	90	100	90	80	90	100	93
210	66	63	90	100	90	90	80	80	90	90	90	100	90	90
						'								

a circle of equal area, the triangles were chosen with an accuracy of better than 92 per cent.

(2) Immediate substitution of right angle triangles for the equilateral was followed by 93 per cent accuracy. These same right angle triangles were chosen with perfect accuracy when exposed with a horizontal combination of three small circles whose total area equalled that of the triangle.

- (3) Of nine presentations where each card had a configuration of three small designs upon it, in only two instances was the discrimination of the triangular pattern below 90 per cent upon the first presentation; and both of these combinations were accurately discriminated on the second trial after having experienced three small triangles in a triangular configuration.
- (4) In two of three cases where we had a card with three small figures exposed with a card containing four figures (total area of both patterns equal), there is some evidence of a discrimination of the triangular configuration (76 per cent accuracy in trial 110 and 81 per cent accuracy in trial 160).
- (5) The second presentation of three small circles in a triangular pattern with a single large circle of equal area was followed by a jump in accuracy from 34 to 95 per cent in the choice of the triangular configuration.
- (6) The outlined figures were discriminated upon the first presentation with an accuracy of 93 per cent.

As a whole these data support the view that the white rat has the ability to react to qualities inherent in visual patterns. However, the conditions of this last and most important experiment throw some light on other questions.

When the right angle triangle was substituted for the equilateral triangle and then rotated in different positions, many observers remarked about the apparent change in its characteristics. That is, rotation of the right angle triangle to new positions seemed to affect its organization as a triangle much more than similar rotation of the equilateral triangle. Since the rats had no difficulty in making this discrimination we thought it was not necessary to use other types of triangles, but we did change the pattern exposed with the triangles. In this instance (trial 60) the accuracy of the discrimination was perfect.

The basis of the original discrimination between the triangle and the circle might be explained by either of these assumptions.

(1) The rats may have learned to react positively to the triangle, disregarding the circle. If this were true, then when new combinations are presented the rats should jump to those figures which are "most like a triangle."

- (2) The rats may have jumped to the triangle because they were reacting negatively to (avoiding) the circle. There are two possible types of negative reaction to the circle:
 - (a) Definite recognition of the circle as a circle and a figure always to be avoided;
 - (b) Recognition of the circle simply as "not a triangle."

 Whenever new combinations of figures are presented, the first type of reaction should produce a jump away from the circle regardless of the other member of the combination: the second type of

member of the combination; the second type of reaction should produce a jump to the figure or pattern which had least of "not a triangle" at-

tached to it.

Under these conditions we could assume that any configuration of circles would be avoided more regularly or have more of the quality of "not a triangle" in direct ratio as the number of circles was increased. If correct, this might help to account for the perfect accuracy of the 60th trial (although perfect scores have been obtained for a series of ten trials before), and for the 34 and 69 per cent accuracy in trials 70 and 80. But it cannot be used as an explanatory principle when the number of circles in each configuration is equal, nor when figures other than circles are used; for under these conditions it is the total organization of the stimuli rather than the shape of particular units to which the rats must look for their success. Thus the data contained in this table lend support to the idea that even where equal configurations are used instead of single figures, the discrimination is still the result of a positive choice of one of them, rather than the avoidance of the other.

The rats did not react successfully to the triangular configuration of circles in the 100th and 120th trials, although the first presentation (90th trial) had given 90 per cent accuracy. But after three small triangles had been exposed with the horizontal and vertical combination of circles for 20 trials, then the next presentation of the triangular configuration of circles gave an accuracy of 93 per cent (raised from 72 per cent) for the large pattern, and an accuracy of 90 per cent (raised from 55 per cent) for the small one. This very great increase in accuracy between the first and the second presentations is attributed to the influence of training on the triangular configuration of small triangles. Thus it would appear that the reaction to the *configuration* was not perfectly established until the rats had been reassured by looking at each of the separate components. Once the rats were certain that they were to react to the configuration, rather than to the elements of which it was composed, the transfer was relatively simple.

Perhaps the best illustration of this point is contained in a comparison of the results of the 70th and the 190th trials where three small circles in a triangular pattern were presented with a single circle of equal area. In the first presentation the triangular pattern was chosen only 34 per cent of the time, while the second time it was chosen with an accuracy of 95 per cent. The uniformly high accuracies in the choice of triangular configurations of squares and rectangles also help to establish the above statement as correct.

We recognize that there are several other ways in which the "concept" could have been tested, and that these data open up a number of important problems for which no solution is advanced. But under the conditions of this experiment, we feel that we have demonstrated the rats' ability to perceive identity in diversity, to react to qualities inherent in a particular pattern, and to exhibit a type of behavior which, had it occurred in man, would have been assumed to be representative of "higher mental processes."

Experiment IX. Training and test of reactions to triangles and circles in new brightness relationships

After a 15 day rest period during which the average weight of the rats increased to 208 grams, they were given the task of discriminating a black equilateral triangle from a black circle of equal area, both figures being placed on white cards and exposed in a white apparatus. This was to determine whether the behavior reported in Experiment IV might not be altered by specific training with these new brightness relationships.

In the previous eight experiments of this study as long as the figures were white, placed on black cards and exposed in a black apparatus, there was no need to worry about the old criticism that the rats might be reacting to the background upon which the designs were exposed instead of to the figures themselves. Since the background is a flat black and is broken only by the two white geometrical figures, any discrimination between the two must be dependent upon the differences between them. This is true regardless of whether the rats perceive the white figures as objects in a foreground, or as holes in a background.

If the figures were black, placed on white cards and then exposed in a black apparatus; or if we were to use white figures placed on black cards, which were in turn exposed in a partially white apparatus set up in a dark room, we would have situations more nearly approximating the conditions under which the animals of two decades ago were required to work. Under these conditions the animals were confronted with large outer figures which were identical in shape and color, and concealed within themselves the geometrical figures to which the animals were supposed to react. It should be remembered that most of the experimenters of that time were forced to present hypotheses in keeping with their negative results, and that these hypotheses are valid only so long as positive evidence of form discrimination was not obtained.

After the first 20 trials on experiment IX, work with rats 3, 8 and 11 was discontinued because of the extremely long time they took before jumping. No. 1 rat was eliminated after completing 430 trials because it developed some sort of an eye infection which caused the cornea to burst, rendering it unfit for further experimentation. Each of the remaining seven animals was given 650 trials on this combination of figures (100 more trials than they had had on the original pattern in table 2).

The data contained in table 13 may be summarized as follows:
(1) At no time during the 650 trials did the group accuracy exceed 79 per cent, showing that as a whole the dis-

crimination was not perfected.

- (2) Only two rats attained the standard of 90 correct jumps out of 100. Rat 9 met the criterion after 400 trials, and rat 10 after 650 trials. It will be recalled that rat 9 made 90 per cent accuracy on this same combination upon its first presentation some 2050 trials earlier (table 5, trials 230 to 240).
- (3) Rat 6 at one point made 85 correct jumps out of 100 trails, but that accuracy was not maintained.

TABLE 13

Discrimination between a black triangle and circle exposed in an all white apparatus

The rats were given a two weeks rest after completing the trials recorded in table 12. The three slowest animals were then eliminated (Nos. 3, 8 and 11) and the remaining ones set to work in an apparatus the exact opposite of that encountered in table 2. Every part of the apparatus that was previously black is now white, and the white portions are now black. Asterisks indicate the point at which rats met the standard of 90 correct choices out of 100.

	CAI	RDS	PER CENT OF CORRECT CHOICES										
TRIAL	Posi- tive	Nega- tive	1	2	4	5	6	7	9	10	AVER		
50	32	36	58	56	54	40	54	56	56	50	53		
100			66	58	58	62	76	54	86	64	66		
150			68	70	58	68	66	68	84	74	70		
200			74	68	62	58	72	82	76	82	72		
250			66	70	62	70	70	68	78	78	70		
300			78	66	68	58	76	76	80	76	72		
350			62	74	58	54	60	64	88	88	69		
400			68	70	52	70	78	70	92*	80	73		
450				78	48	76	82	80	96	90	79		
500				66	52	46	88	70	100	88	73		
550				74	68	66	82	76	100	86	79		
600				54	70	70	76	64	96	86	74		
650				62	72	46	74	64	98	94*	73		

A comparison of the data contained in table 2 and table 13 shows that the group accuracy to the white figures exposed in a black apparatus was 92 per cent in the last 50 of 550 trials, while the response to black figures in a white apparatus after 650 trails was only 73 per cent accurate.

This probably should *not* be interpreted to mean that the white figures have a higher stimulating value than the black ones.

Before making such a statement it would be necessary to train two comparable groups of rats from the very beginning, one on the dark and the other to the light figures, because we cannot tell what the effect of this long training period to the white figures has been. If, during the training on previous problems, the rats had established a reaction to white figures, it is conceivable that they might require a longer period to learn to react to black figures because of the interference.

In addition, it is the writer's opinion that any test which comes after such a long experimental period, during which the animals were always under-fed, would be productive of lower scores. We would hardly expect a man who had been suffering from chronic inanition for a half or more of his life to make scores in his old age which would be comparable to those he could have made when he was younger and in better physical condition.

With respect to the efficiency of black and white as stimuli Weidensall reports,

(1) Black and white are both visible against the background of our box; but they are not equally so. Their effectiveness varies as 1:2: white:black. That is, it takes twice as long to learn the problem of following black alone as it does to follow white alone. Wherefore, (2) when the two are supposedly involved only the white is used because the black is so much more difficult to perceive. And after learning the typical discrimination test, only the white is efficient. Thus the standard discrimination method in a typical instance has reduced itself to one of simple recognition (14, p. 58).

This report leads the present writer to conclude that Weidensall's black and white stimulus combinations were exposed in an apparatus in which the background was a *gray* of a certain brightness, and that it was fairly dark, approaching more closely black than white, for "black and white were both visible against the background of our box, but they are not equally so."

Obviously it is impossible for white or black figures to have equal stimulating value under these conditions, and results so obtained are not comparable with those obtained where two *white* figures were exposed in a *black* apparatus, or two black figures

exposed in a white apparatus. That Weidensall recognized this point is indicated by her statement, "Since the standard discrimination test is one whereby the existence of differing sensory qualities are determined in terms of their efficiency in conduct, it is a serious criticism if the conditions of our experiments have not been such that both the stimuli are inevitably involved and that the chances for their efficiency are equal" (14, p. 58).

The two rats that had successfully adapted to black figures in a white apparatus (table 13) were now given a further test to see

TABLE 14

Test for a positive reaction to triangles regardless of the black-white organization of the pattern

The shoice is entired and the rest would occure food by jumping at either

The choice is optional and the rats would secure food by jumping at either figure.

AVERAGI	CORRECT	PER CENT	NEGATIVE	POSITIVE	TRIAL	
AVERAGI	10	9	NEGATIVE	FOSITIVE	INIAL	
		paratus	White app			
25	30	20	39	41	10	
95	90	100	27	1	20	
95	90	100	36	35	30	
100	100	100	36	33	40	
		paratus	Black app			
85	80	90	36	32	50	
90	80	100	36	34	60	
100	100	100	27	1	70 1	

whether this new reaction had been added to their previous repertoire or whether the earlier discriminations had been destroyed. These data are presented in table 14 and may be summarized as follows:

(1) The reaction to cards 41 and 39 would seem to indicate that the rats were influenced most by the inner white figures, and were reacting positively to the *inner white* triangle instead of the outer black triangle. In previous tests (table 5) the rats had responded to the *outer white* triangle.

- (2) In the 20th trial, the 95 per cent accuracy in the discrimination of the white triangle provides still further assurance that these rats could react to the inner figure of the combination. In the previous test (table 5, 210 and 220th trials) the accuracy was but 62 per cent.
- (3) The almost perfect accuracy in the discrimination of two new positions of the black equilateral triangle (30 and 40th trials) implies that, once the rats have learned that a black triangle is the same as a white triangle, they will be able to transfer immediately to all positions of the black figures without any repetition of the long training period that was needed to establish a discrimination to all positions of the white figures. As soon as the reaction to the color (black—white) is established, there is no need of further training on previously learned patterns of the opposite color.
- (4) Presentation of black figures on white cards which were exposed in the black apparatus (trial 50) lowered the accuracy of the discrimination to 85 per cent. In this case there is no doubt but that the rats were responding to the *inner black* triangle. The only previous test of same pattern (table 5, trial 130) had given but 45 per cent accuracy.
- (5) A black triangle, rotated 30 degrees to the right, drawn on a white card and exposed in a black apparatus, was discriminated with 90 per cent accuracy. The rats had never seen such a pattern before.
- (6) Presentation of the figures to which the animals were originally trained (white equilateral triangle, apex up, and a white circle of equal area, both placed on black cards and exposed in a black apparatus) was followed by a perfect reaction to the triangle, indicating that the very first discrimination established had not been destroyed during the long training on other patterns.

The evidence contained in this experiment certainly emphasizes the additive nature of these reactions, and seems to indicate that the acquisition of each new habit, so long as it is not antagonistic. makes it that much easier to acquire others. A general interpretation of these data reveals that the rats are not necessarily limited in their discrimination to the outer (most inclusive) figure of a particular color in any pattern, but that they can learn to discriminate a particular figure regardless of its color or its position in the total configurational pattern.

TABLE 15

Rank order on various sections of the experiment

The rank in section I is determined by the accuracy in table 2 where the rats were perfecting a discrimination of a white equilateral triangle in a single position. Section II gives the rank on various test situations represented in tables 3, 4 and 5. Section III gives the rank as determined by accuracy in tables 6, 7 and 8 where the rats were learning to react to white triangles in new positions. Section IV gives the rank as determined by the accuracy on the various test situations of tables 9, 10, 11 and 12.

		Rank		
RAT	SECTION I	SECTION II	SECTION III	SECTION IV
1	11	11	3	2
2	5	6	8	10
3	4	9	1	5
4	7	10	9	6
5	9	4	2	1
6	1	2	5.5	7.5
7	10	8	7	7.5
8	6	3	5.5	9
9	2	5	4	3
10	3	1	9	4
11	8	7	11	11

VI. DISCUSSION

Before turning to the results of other experiments, there are certain interconnections between the various parts of this study that should be stressed.

The rank order for each of these rats on the various combinations of figures has been determined, and it brings to light some facts which have an important bearing upon our interpretation of the rats' behavior. Rather than to give the rank order on each combination of figures, we have grouped the data where the problems are somewhat alike, and will present only the rank for those groups. The final order for any one rat is obtained by summation of its rank on all of the separate problems within that group.

Where the rats continued to work on a problem until they met an arbitrarily established standard, it is evident that the final accuracy would not present much variation; so rank orders were determined on the basis of the per cent of correct choices in the total number of trials given to that particular problem.

These data are contained in table 15 and may be summarized as follows:

- (1) The rank assigned to the rats in section I does not entirely agree with that previously given in our summary of table 2. The reason for the change is this. In table 2 the rank was determined according to the order in which the rats met the standard of 90 correct jumps in 100 trials, while in table 15 the rank is determined by the percent of correct choices in the total number of trials given to that particular problem. Six of the rats have the same rank by either method, and no one is displaced more than two places.
- (2) Of the rats (2, 3, 6, 8, 9 and 10) with various amounts of overtraining on the first problem, only rat 3 was able to improve its rank significantly when they were required to learn new triangle positions (section III). This rat had the least amount of overlearning, amount to but 50 trials. The rank of the others became lower with respect to their relative position in the group, which would seem to indicate that overlearning on the initial problem was detrimental and interfered with the learning of subsequent positions of the triangle.
- (3) If we consider the change in rank between sections II and III, there are four cases that stand out with rather startling clearness. Rats 10 (150 trials overlearning) and 6 (300 trials overlearning) which held first and second place respectively in section II were relegated to ninth and 5.5th rank. Rats 1 (no overlearning) and 3 (50 trials overlearning) which held eleventh (lowest) and ninth place respectively, came up to third and first place.

These radical changes in rank may be caused either by the overlearning and automatization of the reactions

to a particular position of a white equilateral triangle early in the experimental period which interferes with later reactions, or we might assume that these rats were · not reacting to the same things to start with. That is, the rats which had high ranks on the first sections where the triangles were presented with apex up, may have learned to react primarily to the position of the brightness pattern, and when this position was changed the accuracy of their reaction was destroyed. The rats with the lower ranks (consequently but little or no overlearning) may have been reacting in part to the quality of triangularity, and since they were given no additional training to establish a reaction to a particular position, they were not so disturbed when the new triangle positions were introduced. The general trend of the rank on successive sections of table 15 lends some support to this latter view.

Rat 11 which was in seventh place in section II dropped to eleventh (last) place in section III.

- (4) The most interesting case in section IV is that of rat 10 whose record shows that it had difficulty in learning the new triangle positions (ninth rank) but that when it was tested for the abstraction it was in fourth place.
- (5) A comparison of sections II (tests of size and brightness relationships) and section IV (test for the abstraction of triangularity) shows a pronounced shifting in rank with rat 1 improving nine points and rat 8 falling off six points. For that part of the study represented by table 15, rats 1 and 5 showed steady improvement while rats 2 and 6 grew steadily worse.

Although we have demonstrated that these rats had established a positive reaction to the triangular figures and that they were not jumping to the triangle merely because they were avoiding some other figure, we do not wish to imply that both figures were not noticed or that the chances for their effectiveness were were not equal. Observation of the animals' behavior while on the jumping platform certainly dispels the idea that they only

looked at one figure, for the comparison (made easier by substitution of a rectangular platform for Lashley's circular jumping stand) involves running to the front of one, then in front of the other figure. Changes in the designs exposed in the apparatus accentuate this behavior.

In addition, the accuracy of the reaction to the triangle varied as the dimensions of the negative figure approached those of the triangle. That is, the accuracy of the discrimination is lowered when an 8 cm. equilateral triangle is exposed with a rectangle of equal base or altitude (total areas remaining equal). This would indicate that the rats were looking at both of the figures. At different times throughout the study we have varied both the positive and the negative stimuli, even to presenting configurations made up entirely of negative elements (table 12) and the rats still reacted positively to the triangular configuration of circles.

With respect to the rats' ability to form concepts, Weidensall reported in 1912, "we found that the variation of position was a confusing factor and that though complete abstraction of quality from position is entirely possible for us, it is extremely difficult, if at all possible, for the rat" (14, p. 59).

In 1913 Hunter stated that "Animals do not discriminate form in the abstract sense in which Bingham uses that term.... I would go farther and present the hypothesis that all animals below man have only a more or less crude pattern vision and that this probably applies also to a varying period of human childhood" (10, p. 330).

This view seems to have been pretty generally accepted and it was not questioned until 1928 when positive discrimination of geometrical figures was reported. Since that time Fields (4, 5, 6 and 7) and Lashley (12 and 13), in studies in which the acuity of the visual reaction was the principal point under investigation, have reported positive discrimination by a number of rats.

But it is the writer's opinion that statements concerning the rats' supposed inability to establish abstractions have not been adequately tested in any of the previous studies. In an earlier paper we emphasized the importance of drawing no conclusions about the rats' ability to form concepts until an experimental procedure which would give the rats at least an equal chance with human subjects had been devised. We believe that the technique set forth in this experiment is the first to give the rats an opportunity to have triangle experiences which approximate those of a human being, and that this study is the first to really test the rats' capacity to form concepts.

VII. SUMMARY

Eleven white rats have been given a total of over 40,000 trials to 80 different stimulus cards which were presented in more than 240 separate combinations. During this period data were gathered on: (1) The development of the concept of triangularity; (2) the essential nature of the discrimination; (3) the reaction to white-black relationships; (4) the figure-ground relationship.

Formation of the concept

The various steps in this training will be discussed in the order in which they occurred.

- (1) Each rat was first trained to discriminate a white equilateral triangle, apex up, from a white circle of equal area with an accuracy of 90 per cent (table 2). Six of the eleven animals were given various amounts of overtraining, which seemed to be effective in establishing a reaction to this particular position of the triangle, but was detrimental so far as establishing a reaction to triangularity was concerned.
- (2) Variation in the areas of the figures did not destroy the accuracy of the discrimination (97 per cent) so long as the triangle was presented with the apex up (table 3). The rats with the most overlearning on the previous problem were most accurate in discriminating various sizes of these figures.
- (3) Various positions of the white equilateral triangle when presented with a white rectangle, cross and square of equal area were chosen but 28 per cent of the time. (This is as severe a test as has been made in any earlier

study, and previous experimenters have been content to stop at this point without going any further in their investigation of the reaction.) At the same time, the triangle in its original position was chosen with 94 per cent accuracy when presented with these same figures (table 6).

The rats were then given 1050 trials to learn to react to 24 different positions of the white equilateral triangle when presented with a white circle of equal area (tables 7, 8 and 9). Although the direction as well as the amount of the displacement (rotation to right or left of the original position) affected the accuracy of the discrimination, there was a great reduction in the number of trials required to learn each successive position of the triangle (580 trials for the first position, while the last eight of 24 positions required none).

The rats were then tested with combinations of the same three triangle positions and the rectangle, cross and square used in table 6. The accuracy jumped from 28 to 90 per cent (table 10), although the rats had had no training on these combinations after their first test in table 6.

Then 20 different positions of the white equilateral triangle were presented with nine other figures (table 11) and the triangles were chosen with a total of better than 90 per cent accuracy for the 200 trials. The combinations productive of the lowest accuracies contained figures whose horizontal and vertical dimensions were identical with those of the triangle. Thus in a situation where the rats were given an opportunity to learn to react to more than a single position of the triangle, they were highly successful.

(4) When a white right angle triangle was presented in eight different positions, the rats chose it at once (no previous training) with an accuracy of 96 per cent, showing a positive transfer from the equilateral triangle and a possible abstraction of triangularity.

(5) The first ten trials on a triangular configuration of circles in combination with a horizontal configuration of an equal number of circles produced a reaction to the triangular pattern which was 90 per cent accurate (table 12). The accuracy of the reaction to various sizes of the configuration was not perfected until after 20 trials on a triangular configuration of small triangles. Thereafter a triangular pattern was always chosen with an accuracy of 90 per cent or better regardless of the figures of which it was composed.

The reaction to combinations of cards with an *unequal* number of figures, indicated that the rats would eventually learn to react to the triangular configuration in such cases (table 12, 81 per cent accuracy on trial 160, and 95 per cent accuracy on the 190th trial) but this "number concept" should be made the subject of a special investigation.

This work with configurations has demonstrated that the rat can react to qualities inherent in a particular pattern, and that it can perceive "identity in diversity." The rat can react to the total organization (Gestalt) of a pattern without previous training to that particular pattern, but this behavior has been built up as the result of its earlier experiences with "elements."

Nature of the discrimination

This discrimination was essentially a *positive* reaction to the triangular designs, and not the result of an avoiding reaction to the other figures. Both stimulas cards were inevitably involved and the chances for their effectiveness, so far as mere stimulation of the retina is concerned, were equal; but the rats picked out and jumped to the card which had the triangular organization upon it.

The Lashley "jumping type" of apparatus (12) produces more of a positive reaction to a particular figure than our older "running type" apparatus (5 and 6) in which the avoiding reaction to the negative figures was about as strong as the approaching reaction elicited by the positive figure, and is almost the exact opposite of Borovski's four-units-double-choice-apparatus for

which he reports, "(2) die Ratten sich mehr an negative als an positive Merkmale halten und also mehr etwas *nicht zu tun* als etwas zu tun lernen;" (1, p. 564).

White-black relationship

These rats were originally trained to react to white figures placed on black cards and exposed in a black apparatus (table 2), and with the exception of a few test trials in table 5, the first 35,000 experiences emphasized figures of a particular brightness. Thus it is to be expected that the rats would react only to simple white figures as long as they were placed on black backgrounds.

But the evidence contained in table 13 would seem to indicate that these rats were capable of *learning* to separate the brightness from the shape of the figure, and could then react to triangular figures regardless of whether they were white and exposed in an all black apparatus, or black and exposed in an all white apparatus. This is not in agreement with the results reported by Borovski (1 and 2).

Figure-ground relationship

As a result of the training to react to simple white figures exposed on a black ground (table 2), when more complex patterns were presented there was a tendency for the rats to react to the outer figures regardless of color; but an acceptable discrimination (90 per cent or better) could only be made when the outer figures were white, and triangular and circular in shape. The rats were not able to react correctly when the triangles were black, or when the triangles were the *inner* figures of the pattern (tables 4 and 5). These factors probably account for the negative results reported by other experimenters which we have reviewed in an earlier paper (7).

After a training period on black figures exposed on a white ground (table 13), the rats still showed a preference for white figures (probably due to the 35,000 trials with such figures) although they could now react correctly to the cards containing the triangles regardless of their color, or their position as the inner or outer figure of the total pattern (table 14).

Technique

Due to the limitations imposed by the apparatus and method used in the present investigation, we are not able to state definitely whether or not the white rat is capable of reacting to "triangularity" from the very start, that is, that the rat already possessed the concept before the experiment began.

But to those who would argue that this technique was essentially additive in nature, and that such abstraction as we have demonstrated only comes after many previous experiences with "triangularity," let me state that we have no good experimental evidence to prove that this is not also the case with man.

VIII. CONCLUSION

When white rats are given a training period specifically designed to provide a large number of different "triangle experiences," the rats are able to perfect a type of behavior which is fully described by the implications inherent in our use of the term "concept."

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¹ The next paper of this series will present an apparatus and technique which were developed to eliminate many of the time consuming factors, and to provide a simultaneous control of many more variables than is possible in the present study. In general, the results of 35,000 trials given 21 white rats in the development of the new apparatus given comparable results in one-half the number of trials needed on similar problems investigated under the present method.

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CONDITIONING FINGER RETRACTION TO VISUAL STIMULI NEAR THE ABSOLUTE THRESHOLD¹

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The possibility of conditioning finger retraction to weak visual stimuli was investigated for several reasons. Some estimate seemed worth while as to how weak the visual stimulus can be and still prove effective in conditioning: though Froloff succeeded in securing data on the amount of brightness-difference necessary to elicit a conditioned response, there appears to be little known concerning requisite absolute brightness. Second, the question of the conditionability of stimuli which are below the sensory threshold has not been settled; definite information on this point would be of theoretical importance. It may be that awareness of the conditioned stimulus is not an indispensible factor in conditioning. From the introspection of his subjects and from a comparison of voluntary with conditioned response latencies, Ignatius Hamel concluded that the conditioned response is always dependent upon consciousness.3 But that conclusion now seems unwarranted for there were no test trials with imperceptible stimuli. Third, the technical need, particularly in comparative psychology, for an equation of feasible threshold measurement methods has not been satisfied. Ever since Wat-

¹ This investigation was carried out in the Laboratory of Psychology, Institute of Human Relations, Yale University.

² Razran, H. S. and Warden, C. J.: Sensory capacities of the dog as studied by the conditioned reflex method. *Psychol. Bull.*, 1929, 26, 202–222.

³ Hamel, I. A.: A study and analysis of the conditioned reflex. *Psychol. Monog.*, 1919, 27, No. 118, 44-63.

son in 1915 proposed the conditioned response technique to replace the usual discrimination methods and verbal report in various sensory fields, the need has been evident. As early as 1916 Hamel planned to compare threshold values obtained by the conditioned reflex procedure with others secured by the usual "introspective" methods, but the technical difficulties were never surmounted and the necessary experimentation was never performed. In that connection we have attempted to obtain absolute thresholds simultaneously by conditioned response technique and by psychophysical judgment with the method of constant stimuli. An equation of techniques for determining difference-thresholds, using the method of just noticeable differences, has been attempted by other investigators.

APPARATUS

The principle instrumental requirements were: first, to give a momentary electric shock to serve as the unconditioned stimulus to finger retraction; second, to present silently a visual stimulus (the conditioned stimulus), adjustable over an intensity range

⁴ Watson, J. B.: The place of the conditioned reflex in psychology. *Psychol. Rev.*, 1916, 23, 89–116. He must have felt that conditioned response was in general preferable and he seems to have implied that it is as delicate an indicator of sensory discrimination as the subject's verbal report. Cf. Op. cit., 101; Behavior, an introduction to comparative psychology, 1914, 67–8; and Psychology from the standpoint of a behaviorist, 1919, 35–8.

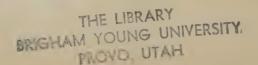
Anrep seems to agree with the principle that different forms of response may be equally sensitive as sensory threshold indicators. "Dogs possess a full pitch discrimination power and if a suitable method is used it can be observed on muscular and salivary reflexes equally well." J. Physiol., 1920, 53, 385.

Anrep's view was stated in opposition to a suggestion by H. M. Johnson. Later the latter wrote quite generally and positively that "the value yielded by the (threshold) determination is strictly relative to the kind of response employed." A result of Warner Brown's from a lifted weight subject was cited; vocal response was more advantageous than manual response in determining a differential threshold. Psychol. Rev., 1929, 36, 265. Also Behavior Monog., 1913, 2, No. 3, 3.

Such diverse views, and the extent to which the conditioned response technique has been used, emphasize the need of experimental comparisons of methods.

⁵ Op. cit., 24-26.

⁶ Graham, C. H. and Nafe, J. P.: Human intensity discrimination with the Watson-Yerkes apparatus. J. Genet. Psychol., 1930, 37, 220-231.



sufficient to include the absolute threshold; third, to provide a mechanism for controlling the time relations of shock and light stimuli; and fourth, to produce a graphic record of the finger retraction, the subject's report concerning perception of the light stimulus, and the incidence of shock and light. The means of fulfilling these requirements may be described by reference to figure 1.

A vertical division near the middle of the figure represents the wall between adjacent rooms. The subject occupied the dark-room at the left and the experimenter the lighted room at the

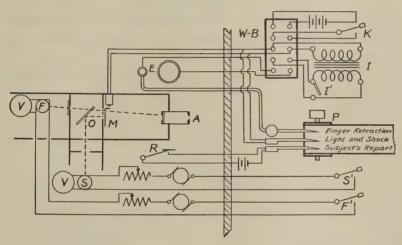


FIG. 1. SCHEMATIC PLAN OF APPARATUS

right. During experimentation the subject sat with his dominant eye at the artificial pupil, A, his head supported by forehead and chin rests, his left hand at the report key, R, his right hand on the shocking electrodes, E, and his body steadied by dual armrests. The experimenter sat before the stimulus control switches, F', I', K, and S', and the polygraph, P, which recorded the stimuli and responses.

The source of shock was a Porter inductorium, I, the primary of which was connected with a 6 volt storage battery and the secondary with the hand-finger electrodes, E. The subject's right arm was comfortably supported by the armrest, the heel

of his hand resting on the larger electrode, his middle finger on the smaller electrode. The break shock, localized in the middle finger, was employed, and the intensity was adjusted to produce very definite retraction in the given subject.⁷

The source of visual stimulation was a tungsten projection lamp, S, operated at a fixed voltage. Intensity was varied by moving the lamp back and forth on a track in a long box. Light from the lamp passed through a daylight filter and fell upon the magnesium oxide surface, O; thence it was deflected toward the subject's eye at the pupil, A. The aperture between O and M defined the stimulus field, the diameter being 1.5° visual angle and the form semicircular. The brightness range was adjusted to include the threshold by the use of a reducing filter in the observation tube. A second lamp, F, served as the source of a fixation light. The beam to the eye passed through a daylight filter, ground glass, and a circular hole in the partition containing the stimulus aperture. The size of this hole determined the size of the fixation stimulus, i.e., 0.5° visual angle. Brightness was adjusted to a low but somewhat super-threshold value. This

⁷ An induction coil was used because it seemed sufficient for the purpose and was readily available; it is not an ideal source of shock. In the present case the experienced shock intensity exhibited a tendency to fall off noticeably during the first few administrations in a series. Measurements with both galvanometer and milliammeter showed that there was considerable though gradually decreasing fall in the induced e.m.f. at the secondary terminals, a result, doubtless, of rising temperature and consequent increased resistance. After a time the secondary output reached a relatively constant level as a result, presumably, of attainment of temperature equilibrium. One set of galvanometer readings ranged from 15 scale divisions at the start to 13.5 at approximate constancy while the corresponding range of milliammeter readings was 8.25 to 6.8. Probably the fall in subjective intensity was a result more of this drop in physical intensity than of adaptation.

Incidentally it is interesting to consider this regular decrement in physical shock in connection with the regular decrement in response found in the very numerous physiological studies of electrically stimulated nerve-muscle preparations; if an inductorium is used and the stimulus intensity is not sufficiently controlled, the results are of little value.

We adopted the expedient of warming up the inductorium just before the beginning of a series and during the rest period. There was then, for our purposes, little need of inductorium adjustment during the series itself. Shutter magnets and control solenoid were warmed up at the same time.

fixation light appeared on the dark background a fraction of a degree above the stimulus light. Either light could be switched on or off independently by means of S' and F'.

Whenever the light stimulus was presented to the subject the manual switches S' and F' were already closed, and the stimulus was automatically exposed by the opening of a magnetic shutter, M. The chief shutter requirements were dependability and silence. The mechanism was located wholly within the closed light box and included but one moving part; even with the box open the operation of the shutter was inaudible. Tests in every experimental session provided demonstration of adequacy.

This shutter consisted of a light, sector-shaped pendulum, about four inches long, mounted in cone bearings. When at rest the pendulum covered the stimulus aperture. Two electromagnets were fixed at different distances above the point of rest but with poles along the path of the iron end of the pendulum. Whenever the circuit through the magnets was closed the first magnet initiated the upward pendulum movement and the second became increasingly effective as the pendulum-end approached its pole-face. At the point of apposition the shutter was held without sound or contact while the aperture was wholly exposed for the duration desired. An arc-shaped slot prevented occlusion of the fixation light regardless of the position of the shutter.

Time relations of the light and shock stimuli were controlled by a Ward-Bennett solenoid, W-B. s This device was connected electrically with the inductorium, I, the electrodes, E, and the shutter, M. Closing the key, K, energized the solenoid by means of which the circuit through the shutter-magnets was made and that through the inductorium-primary was broken. In some series the solenoid was set to expose the weak visual stimulus for about 2 seconds, in others for 1 second, and in still others for about 0.5 second. The break shock was momentary, of course.

In order to present the light alone, in the test trials for conditioning, the experimenter shortcircuited the secondary of the

⁸ The writers are indebted to L. B. Ward and G. K. Bennett for use of this instrument and also for construction and experimentation which resulted in a satisfactory magnetic shutter.

inductorium before energizing the solenoid, that is, he closed I' before K. In some control trials the shock was administered without the light by opening S' before closing K; in others, both shock and light were eliminated by manipulating both I' and S' before K.

The graphic record of finger retraction, subject's report, and incidence of light and shock, was produced on stylograph paper by a Ward-Bennett polygraph, P. The drum was driven by a synchronous motor at the rate of 5 mm. per second. The marker recording the finger retraction was actuated by a Marey tambour connected by copper tubing with another tambour below the finger-cup electrode. Sudden release of a slight pressure on the finger electrode was sufficient to produce marked movement of the recording point. A magnetic marker recording incidence of light and shock was connected at the same terminals of the solenoid case as the shutter and the inductorium. The subject's signalled report of judgment concerning the light was recorded by a second magnetic marker connected with the key, R.

PROCEDURE

A procedure was planned with the hope of securing indications concerning the points already mentioned, viz., the conditionability of weak and subliminal stimuli, and the comparability of the conditioned response technique and psychophysical judgment with the constant method.

The seven subjects of this study included one undergraduate, four professional psychologists, and also the writers. Three had served recently in a long experiment on visual thresholds; two had had considerable experience in reacting to shock stimuli; three were not aware of the nature of the experimental problem.

The experimentation took place during May, June, and July, 1932. Each subject served in 12 sessions of about an hour's duration. These came, with a few exceptions, on successive days. There were three types of session: a preliminary instructional session for adjustment of subject, apparatus and stimuli; four normal sessions without shock, devoted to the determination of the absolute visual threshold by the method of constant stim-

uli; and seven *conditioning sessions* in which the shock was associated with the light stimulus, and in which the psychophysical threshold was also determined. Two of the normal sessions preceded and two followed the conditioning sessions.

Preliminary sessions. The forehead and chin rest were adjusted to bring the dominant eye in proper relation to the artificial pupil, the settings being measured by vernier calipers to facilitate accurate resetting. The subject was practised in picking up the fixation light, observation of the stimulus light, and in operating his report key; one closure indicated attainment of fixation and two closures indicated perception of the light stimulus. He was instructed to be unconservative in his judgments, that is, to report perception of the stimulus in all cases of higher certainty than a guess. The effect would be to yield maximally low values for the threshold and so make more positive any cases of conditioned response to sub-threshold stimuli that might occur. A preliminary adjustment of the shock intensity was made and the subject was practiced in placing his right hand on the electrodes. Finally, the experimenter provisionally selected, by trial and adjustment, the five constant intensities of the visual stimulus to be used subsequently.

Normal sessions. After 15 minutes dark adaptation the subject was given a ready signal and the fixation light was turned on; after picking up fixation, the subject gave a ready signal to the experimenter. The stimulus was presented after a variable period of two to six seconds; the fixation light was then turned off and the subject gave his report concerning perception of the stimulus. An assistant promptly set the stimulus light for a new intensity and 30 seconds after disappearance of the fixation light gave the ready signal for the next stimulation. Remaining in his seat and in darkness, the subject was given a 5 minute rest in the middle of each session, and during this period as well as before and after each session the settings were checked and the apparatus tested. After the first normal session the subject was encouraged to report any experiences or difficulties that he might have noted.

Each of the four normal sessions consisted of 36 stimulations.

Thirty of these were of 6 trials at each of the 5 intensities, and the other 6 were controls in which the light source was turned off but the shutter opened in the usual way. All intensities and controls were presented in a predetermined random order.

Conditioning sessions. Aside from the administrations of shock, the procedure in the seven conditioning sessions was, as nearly as was practicable, the same as that in the normal sessions. The subject was instructed to try to maintain fixation upon the fixation object, to watch carefully for the visual stimulus, and to let his right hand take care of itself.

In four of the conditioning sessions (Series A) there were 5 trials for conditioning and 6 controls; each of the remaining three conditioning sessions (Series B) contained 10 test trials (2 at each of the 5 intensities) and no controls. The order of series was A, B, B, A, B, A, A.

Five "controls" consisted of opening the shutter with no stimulus light but presenting fixation light and shock as usual. Such control stimuli at the beginning of the experiment should disclose any tendency to pass affirmative judgments at too low a level of confidence, while the controls at the end would help to validate what were expected to be the most important data. The sixth control was without shock or stimulus light, only the fixation light being presented. This really served as a test to determine whether or not a conditioned response had been established to any possible click in the shutter or to some other extraneous cue produced by the mechanics of presenting the light and shock stimuli.

A procedural summary in terms of the numbers of normal and conditioning trials is given in table I.

The time relations of the stimuli were varied because of their known importance in conditioning. For three subjects the duration of the light was made about 2 seconds, for two subjects about 1 second, and for the other two about 0.5 second. In all cases the stimuli were arranged so the shock would occur just before the light was extinguished.

Several factors in the experiment seemed inherently unfavorable to conditioning. The use of the control stimuli reduced

the opportunity for reinforcement. Even when the visual stimulus was perceived it was so weak as presumably not to be very effective. More striking results perhaps could be secured by conditioning to fairly intense light in a number of trials and then testing with the weak stimuli. We did not do this because it seemed to us an interesting but a different problem. We were particularly interested in using weak stimuli in the conditioning process, not merely in the testing process.

TABLE I

Total number of trials for a given subject in the normal and conditioning series

NORMAL SERIES—LIGHT	CONDITIONIN	G SERIES	
	Light—shock	Light	
1	24	35	10
2	24	35	10
3	24	35	10
4	24	35	10
5	24	35	10
0 (control)	24	20	4
otals	. 144	195	54

There were several unavoidable irregularities in the procedure which can best be pointed out later in connection with the description of results.

RESULTS

Before presenting the quantitative data it seems desirable to outline the more qualitative results concerning the nature of the psychophysical judgments and the conditioning process, for the validity of the study as a whole obviously rests upon those two things.

Psychophysical judgments. The subject had not been told to guess but he had been instructed to report perception of the light whenever he felt he had seen it, whether or not he was quite certain. Surprisingly enough, the control trials disclosed scarcely any errors, i.e., judgments of light when there was none. In the preliminary session and early normal sessions there were, intro-

spectively and by record, a few cases of confusion of entoptic effects with the stimulus, but the semicircular form of the latter facilitated discrimination despite the fact that the outline never appeared clear-cut at the lowest perceptible intensities. Streaming phenomena were occasionally troublesome in the early sessions, not by confusion with the stimulus but by obliterating it. Each subject used his dominant eye throughout, and retinal rivalry did not seem to be a serious difficulty. In general the effect of duration of the visual stimulus seemed in accordance with what might be expected from the reciprocity principle; stimulation with the shortest duration resulted in higher sensory thresholds as measured in terms of Troland's photon. The effect of the variable time interval between the subject's ready-signal and presentation of stimulus was not so regular, but on the whole the two-second interval seems to have been accompanied by highest sensitivity. All subjects evidenced marked practice effect in the speed with which they attained fixation before each stimulation, maximum proficiency being attained during the first or second normal session. Effects of practice and shocking upon the visual threshold itself were neither great nor regular.

Conditioning process. The instruction was to attend to the light and let the hand take care of itself. Even so there were one or two instances of finger retraction to entoptic light which happened to occur at the right moment in test trials. Before the subject depressed his report key, however, he realized that he had not perceived the external stimulus. He apprised the experimenter of the experience and was credited neither with having perceived the stimulus nor with reacting to an unperceived stimulus. During the first conditioning session several subjects felt a tendency to react to the shock by pressing the light report key, and there were several actual cases of such reaction known to occur. The subjects were cautioned against this response and the tendency seems to have passed completely by the end of the session. Subjects remarked that they felt a tendency to lift the finger in response to the light; some reported an increasing urge to raise it from the time the light appeared to the time it disappeared. A naïve subject remarked that his finger

jumped off of itself even when there was no shock. A sophisticated subject was surprised to learn that he had made three conditioned responses when he thought his finger had not moved during any of the test trials of the session.

There was a comparatively small number of anticipatory reactions, that is, cases in which the finger was jerked off the electrode before the instant at which the shock regularly occurred. This happened in trials both with and without shock. latency of the conditioned response showed great variation in the range from undefined minimum up to about 1 second. There seem to have been several important factors operative but the data have not been systematically analyzed from that standpoint. One or two indications, however, seem quite definite. Latency tended to be less in those reinforcement trials in which the stimulus light was perceived than in those in which it was not. In test trials, when the light alone was experienced, the latency tended to be greater than in reinforcement trials when both light and shock were experienced. But in control trials, when the shock alone was administered, the latency also tended to be greater than in the reinforcement trials; apparently light as well as shock helped quicken response.9 There was, too, some tendency for the lower intensities of light stimulus to be accompanied by longer finger retraction latencies. The longer durations and the higher intensities of light stimulus seem to have been most effective from the standpoint of conditioning. During the two final normal sessions of the experiment the subjects were not required to keep the right hand in position on the electrodes. One who happened to do so, reported a strong tendency to retract his finger when the stimulus light appeared; but this tendency seems to have disappeared quickly. In case of three subjects the conditioned response gradually broke down during the later conditioning sessions, whereas in case of the other four it persisted.

⁹ For a somewhat similar facilitation effect in the relations of the conditioned and unconditioned stimuli, see Hilgard, E. R.: Conditioned eyelid reactions to a light stimulus based on the reflex wink to sound. *Psychol. Monog.*, 1931, 41, no. 184, p. 16, footnote 11.

The polygrams and record sheets show 122 instances in which the finger retraction occurred in the test trials at about the same time or a little after the shock occurred in the reinforcing trials. Such responses are commonly termed conditioned responses and they are so considered in the present study. Still we have no quarrel with those who choose to employ some other term to represent the same type of response.

Conditionability of low visual intensities. Quantitative data bearing upon this question will be found in tables II, III, IV and V. Table II shows the frequency of conditioned finger retractions of each subject at each of the several intensities of

 ${\it TABLE~II} \\ Number~of~conditioned~finger~retractions~of~each~subject~at~each~visual~intensity \\$

VISUAL INTENSITIES		SUBJECTS												
(PHOTONS)	1	2	3	4	5	6	7	TOTALS						
0.007						2	0	2						
0.006						0	0	. 0						
0.005	7	9	4	6	8	2	0	36						
0.004	8	10	3	8	6	3	3	41						
0.003	6	8	1	4	7	0	0	26						
0.002	3	6	0	3	2			14						
0.001	0	2	0	1	0			3						
0.000 (control)	0	0	0	. 0	0	0	0	0						
Totals	24	35	8	22	23	7	3	122						

visual stimulus employed. The intensities are given in the first column of the table; they range from zero to 0.007 photon by 0.001 photon steps.¹⁰ Each subject was presented with five constant values plus the zero or control, the effort being to select a range which would include the subject's absolute visual threshold. Since subjects 1, 2, 3, 4, 5 had somewhat lower thresholds than subjects 6 and 7, lower ranges of stimuli were used on the former.

¹⁰ Great care was exercised in the effort to control adequately the visual stimuli; nevertheless these absolute values may be in error as much as 10 per cent because of the operation of such factors as the fluctuation of lamp voltages, tolerance of reducing filters, inevitable eye movements, and imperfect registration with the artificial pupil.

This difference is indicated by the dashes in the body of the table. Every subject made some conditioned responses to the extremely weak stimuli employed, and no subject responded in the control trials of the conditioning series. The tabular columns indicate a definite tendency for the number of conditioned responses to decrease as the intensity of the conditioned stimulus decreases.

The several unavoidable irregularities in procedure, already referred to, may be best explicated at this point. These irregularities concern only subjects 5, 6, and 7. For them the constant visual stimulus values had to be changed after the commencement of the normal sessions because the experimenter was unsuccessful in the preliminary session in selecting values which would satisfactorily include the absolute threshold throughout the experiment. Subject 5 was started with intensity range 0.005 to 0.001 but this seemed a bit too low and he was raised to 0.006 to 0.002 at the beginning of the first conditioning session. By the end of this session, however, it seemed too high and was reduced to 0.005 to 0.001 again where it remained throughout the rest of the experiment. Subject 6 was also started at 0.005 to 0.001 but by the end of the second conditioning session it seemed desirable to try a shorter duration of visual stimulus for comparison with longer durations used with other subjects. shorter duration, 0.5 second, raised the threshold as measured in photons, and necessitated raising the intensity range to 0.007 to 0.003 where it remained. Subject 7 seemed extraordinarily sensitive in the preliminary session and started the first normal session with range 0.004 to 0.00075. At the end of the second normal session, however, the duration of visual stimulus was reduced to 0.5 second for the same reason as with subject 6. This made the intensity range too low and at the end of the first conditioning session it was increased to 0.005 to 0.001. But by the end of the second conditioning session it was clear that the range was still too low, and it was raised to 0.007 to 0.003 where it remained. Beside these changes in the values of the constant stimuli and in the duration of the visual stimulus, there were several occasions when the intensity of the shock had to be adjusted during

the conditioning series. While these variations in procedure are unfortunate logically, they can scarcely be regarded as affecting the trend or significance of the principal results. To some extent, however, they do affect the specific interpretations of Table II.

The intensity ranges given in that table for subjects 5, 6, and 7 are those which were finally selected and used throughout the last six, five, and five conditioning sessions, respectively. But since there happened to be, during the respective first one, two, and two conditioning sessions, no cases of conditioned responses falling outside the intensity ranges finally adopted, table II is actually correct in indicating the numbers of conditioned responses occurring at every intensity for every subject. The table does not show that whereas the intensity ranges for subjects 1, 2, 3, and 4 remained constant throughout all seven conditioning sessions, they were altered for subjects 5, 6, and 7 as above explained.

Neither does the table show that subjects 6 and 7 had somewhat less practice with the particular duration of visual stimulus finally selected for them, than did the other subjects with the respective durations used by them throughout the experiment. Subject 6 was not started on the finally selected 0.5 second duration until the beginning of the third conditioning session; subject 7 was started on this duration at the beginning of his first conditioning session. Two of the conditioned responses indicated in the table for subject 6 actually occurred before the duration was reduced to 0.5 second.

Bearing in mind the change in duration of the stimulus in the case of subjects 6 and 7, the question can be considered of a relation between duration of stimulus and number of conditioned responses. The average number of conditioned responses from subjects 1, 2, 3, who were given the 2 seconds duration, was 22.3; from subjects 4 and 5, with the 1 second duration, 22.5; and from subjects 6 and 7, with the 0.5 second duration, 5.0. While the latter figure is probably somewhat too small because of the change in duration mentioned above, the probability seems to be that the longer durations were nearer the optimum for conditioning under our experimental conditions.

Whereas table II presents measures of conditionable stimulus intensity in terms of the photon, tables III, IV, V present such measures in terms of three independent determinations of the individual visual threshold. These three tables are exactly alike in form; in each the first column represents 0.25 sigma steps ranging below and above the threshold. The succeeding columns give the frequencies of conditioned finger retractions of each subject at each sigma distance from his threshold. In table

TABLE III

Distribution of the cases of conditioned finger retraction of each subject in relation to his visual threshold as calculated from his normal frequencies

0.25 SIGMA INTERVALS			st	BJECTS				TOTAL
0.20 SIGMA INTERCANDS	1	2	3	4	5	6	7	101111
2.75-2.99		9						9
2.5								
2.25								
2			4					4
1.75	7	10						17
1.5				6	8			14
1.25			3					3
1	8	8						16
0.75				8	6	2		16
0.5			1				3	4
0.25	6	6		4		2		18
0.00					7	3		10
Threshold (RL _N)								
-0.25				3				3
-0.5	3							3
-0.75		2			2			4
-1				1				1

III for instance, subject 1 made 7 finger retractions when the visual stimulus fell in the interval 1.75 to 1.99 sigma; he made 8 retractions at stimulus intensity 1.0 to 1.24 sigma above his threshold; and so on. The last column gives the total number of conditioned responses made at each sigma distance above and below the limen. The distribution of retractions of each subject is really discrete since each subject was actually stimulated with but five visual intensities; the tables simply show the sigma steps on which the several intensities happened to fall.

TABLE IV

Distribution of the cases of conditioned finger retraction of each subject in relation to his visual threshold as calculated from his reinforcement frequencies

0.25 sigma intervals		SUBJECTS												
	1	2	3	4	5	6	7	TOTALS						
2.75-2.99			4					4						
2.5														
2.25	7							7						
2														
1.75	٠.	9	3		8			20						
1.5	8							8						
1.25		10		6				16						
1			1		6	2		9						
0.75	6			8				14						
0.5		8			7			15						
0.25				4				4						
0.00	3			3		2	3	11						
Threshold (RL _S)														
-0.25		6			2			8						
-0.5				1		3		4						
-0.75		2						2						

TABLE V

Distribution of cases of conditioned finger retraction of each subject in relation to his visual threshold as calculated from his test trials

0.25 sigma intervals			st	BJECTS				TOTALS
O.SO SACREM ANTENEY MANY	1	2	3	4	5	6	7	TOTALS
2.00-2.24	7							7
1.75		9	4					13
1.5								
1.25		10	3	6				19
1	8							8
0.75				8	8			16
0.5		8	1			2		11
0.25	6				6			12
0.00		6		4	7			17
Threshold (RL _T)								
-0.25								
-0.5	3			3	2	2	3	13
-0.25		2						2
-1						3		3
-1.25				1				1

Tables III. IV, and V differ from each other in that each is based upon entirely different visual data. The thresholds and sigma's of table III were calculated from the observed frequencies of the four normal sessions without shock; they were therefore removed in time a day or two from the conditioned responses themselves. Table IV is based on the observed frequencies in the shock or reinforcement trials of the seven conditioning sessions; since these trials were intermixed with the test trials they were much closer to them in time. Table V represents the greatest temporal advantage for it is based on the observed frequencies in the test trials themselves. Thus temporally, the order of rigorousness of the tables is V, IV, III, but because of the difference in n table IV may be as important as table V. The data of tables III and V were secured in the absence of shock, and since there was no shock when the conditioned response occurred, these tables seem more significant from that standpoint. In any event, all three exhibit surprising similarity in the general distribution of frequencies of finger retraction; each indicates that intensities ranging from around 3 sigma above the psychophysical threshold to around 1 sigma below it were effective in producing the conditioned reaction.

Inspection shows at once that there were many more retractions in the range above the threshold than below. This is not surprising, however, since it has already been shown (table II) that the higher visual intensities proved more effective in conditioning, and the visual thresholds themselves usually proved to be below the middle of the intensity ranges employed.

For all subjects the visual data were secured by the method of constant stimuli and the thresholds calculated are the 0.50 psychophysical thresholds. The three thresholds for each subject are designated respectively RL_N, RL_S, RL_T, according as they are based on the data from the normal, the shocking, or the test trials. These thresholds and their sigma's were calculated by interpolation formulae elsewhere described and derived.¹¹ Of course, $\sigma_{distr.}$ could be changed into P.E._{RL} if this further sta-

¹¹ Newhall, S. M.: An interpolation procedure for calculating thresholds. *Psychol. Rev.*, 1928, *35*, 49–53, 57–59.

tistical elaboration seemed worthwhile, but as Table I suggests, n was not nearly as large as might be desired, and further elaboration might be misleading.

If it is generally true that repetitive stimuli of near-threshold value are conditionable, one may speculate concerning hundreds of such stimuli which may be effective in everyday life quite without the knowledge of the individual.

Conditionability of subthreshold visual intensities. The preceding tables not only show that a number of conditioned responses were evoked by stimuli below the statistical psychophysical limens but also suggest about how low they were in terms of sigma.

TABLE VI

Numbers of conditioned finger retractions to subthreshold visual stimuli according to each of four criteria of "subthreshold"

CRITERIA OF "SUBTHRESHOLD"			TOTALS					
CAPATRIA CA SUBTRIANDED	1	2	3	4	5	6	7	TOTALS
Below RL _N	3	2		4	2			11
Below RL _S		8		1	2	3		14
Below RL _T	3	2		4	2	5	3	19
trial	1	4		1	1		1	8

Table VI shows the numbers of cases of conditioned retraction to subliminal stimulation with respect to four criteria of "subthreshold." The first three are evident from what has been written above; the stimulus was called subthreshold if it was below the psychophysical threshold $\mathrm{RL_N}$, $\mathrm{RL_S}$, or $\mathrm{RL_T}$. While it seems certain that stimuli which were subthreshold in this definite sense did elicit the finger retraction, too much importance should not be attached to the fact. After all, the "absolute" threshold is the 0.5 point and about half the cases of light perception which fall within the critical range necessarily fall below it themselves. Had the observed frequencies of conditioned response ranged significantly lower than the observed frequencies of light perception in the test trials, then the 0.5 limen computed from the former frequencies would be significantly

lower than that from the latter, and the question of the conditionability of subthreshold stimuli would be answered quite conclusively in the affirmative. Tables VIII and IX, however, will show that such was not the case in the present study.

The fourth criterion, in a sense the most rigorous, was the subject's report rendered immediately following each individual test trial; if the subject then reported that he did not perceive the light it was considered to be subthreshold. As the table shows, there were 8 instances of conditioned response to subliminal stimulation according to this fourth criterion. These, if any, are crucial cases which merit special study for sources of error.

Reinspection of the original records failed to disclose any clerical errors in the elaborated data. Neither did the polygrams lend themselves to ambiguous interpretation for the record of finger retraction was large and clearcut, the actual displacement ranging between an eighth and a half inch.

It is improbable that the subjects were perceiving the light stimulus but not reporting it; not only were they instructed to report affirmatively whenever they felt they saw it, but the calculated thresholds are low relative to those reported by others as secured under somewhat similar conditions, 12 and are of the same order as those secured by one of the writers (N.) in an unpublished threshold study utilizing nearly the same visual apparatus. Still the S could not be instructed to guess and possibly some visual experience was not reported.

Moreover the meaning of the report might possibly vary with the form of voluntary reporting response.¹³ If the manual response actually employed were less sensitive than the vocal response conventionally used in reporting psychophysical judgments, our criterion of imperceptibility might well be criticized. On the contrary and despite Brown's result,¹⁴ we are inclined to

¹² Cf. e.g., Purdy, D. McL.: On the saturations and chromatic thresholds of the spectral colours. *Brit. J. Psychol.* (Gen. Sec.), 1931, 21, 294-6.

¹³ Cf. footnote 4.

¹⁴ Brown, Warner.: The judgment of difference. Univ. of Calif. Pub. 1, 41–51. In lifted weights the advantage seemed to be with the vocal response but there was an opportunity for the manual response to become confused since the weight lifting itself was manual.

believe that the manual response was at least as sensitive as the vocal could have been; but the whole matter might well be the subject of special investigation.

If the subject's attention had slipped from the visual field to the handshock situation a faint light might have passed unperceived because of the lowered intensity due to the lowered attention. The stimulus might have been sufficient still to elicit the conditioned response, but such a stimulus would actually be a subthreshold stimulus!

To the extent that retention is dependent upon vividness, there is the possibility that the subject perceived the weak light but forgot it before he could report it. Since the retention span required was less than 5 seconds and since the subject observed with the instruction and intention of reporting, this memory error seems very unlikely.

One experienced subject felt, once or twice, that he hallucinated the fixation object during the dark-adaptation period. This is the only datum which might suggest the possibility of finger retraction to an hallucinatory light.

In early normal sessions there are known to have been two or three instances of the subject's inadvertently reacting to adventitious light effects of internal origin. Possibly some phosphene or ideoretinal light, not identified by the subject as the stimulus and hence not reported, might still have been effective in setting off the finger retraction. While there is no evidence that such effect occurred during the test trials, either at all or at the right moment, it seems to us to be a possible source of error. It is conceivable, too, that slight adventitious stimuli of other modalities could set off the response, but so far as the physical conditions external to the subject were concerned, this seems to have been almost impossible.

There is the chance that a gradually mounting tension or urge to react might produce the response of itself without specific external stimulus, but that this should have occurred at the right moment on eight occasions seems doubtful. There remains the

 $^{^{15}}$ Cf. e.g., Newhall, S. M.: J. Exper. Psychol., 1921, 4, 222 ff. and Arch. Psychol., no. 61.

possibility of temporal conditioning. This type is relatively slow to develop, however, and that fact together with our specific control against temporal constancy and conditioning makes it seem improbable.

In brief, a number of possible causes for reported imperception have occurred to the writers and some of these could result in artifact; but perhaps the most plausible interpretation of these eight crucial cases is that a really unperceived stimulus was eliciting the motor response, i.e., that the motor response was on these occasions more sensitive than the conscious. Certainly, if the two forms of response were about equally sensitive and were to even a slight degree independently variable, then according to probability theory the one should be somewhat more sensitive on some occasions and the other on other occasions. Under such circumstances it would be strange indeed if unperceived stimuli did not sometimes evoke conditioned responses.

Comparability of the psychophysical judgment and the conditioned response as threshold measurement methods. Most of the results already presented bear upon this difficult problem. The tendency for the frequencies of conditioned response to decrease with stimulus intensity (table II), and the fact that conditioned responses occurred below as well as above the "constant" threshold (tables III, IV, V, VI), suggest fundamental similarities in response trend and the possibility of equating results.

The next step was to compare individually the observed frequencies, or psychophysical judgments, of the constant method with the corresponding frequencies of conditioned response. To the extent that these frequencies approximate each other, we may expect thresholds and probable errors calculated from them to do so. A very simple comparison was made by finding, in the case of each pair of observed frequencies, the ratio of the number of conditioned responses to the number of reported light perceptions. Table VII is arranged to show these ratios in respect to stimulus intensity. In case of subjects 1, 2, 4, 5, who became relatively well conditioned, the ratios approach 1.00 regardless of stimulus intensity. This means of course that the observed frequencies approach equality.

Since the psychophysical judgment was already practiced at the commencement of the conditioning sessions and the conditioned response was not then established, we might expect a progressive rise in the ratios as the conditioned response became more or less gradually established with successive conditioning sessions. Table VIII is like VII except that it is arranged to

TABLE VII
Ratios of numbers of conditioned finger retractions to numbers of reported light
perceptions in the test trials at each visual intensity

RELATIVE VISUAL	SUBJECTS											
INTENSITIES	1	2	3	4	5	6	7					
1	0.78	0.9	0.4	0.75	1.0	0.17		0.57				
2	0.80	1.0	0.3	1.0	0.86	0.5	0.5	0.71				
3	0.83	1.0	0.13	0.67	1.0			0.52				
4	0.75	1.0		0.75	0.5			0.43				
5				1.0			-	0.14				

TABLE VIII

Ratios of numbers of conditioned finger retractions to numbers of reported light

perceptions in the test trials of each conditioning series

CONDITION-	SUBJECTS											
ING SERIES	1	2	3	4	5	6	7	MEANS				
1		1.0		0.75	0.4			0.43				
2	0.86	1.0		1.0	1.0			0.77				
3	0.67	1.0	0.38	0.6	1.0	0.5	0.17	0.62				
4	0.67	1.0	0.33	0.33	1.0	0.43	0.33	0.58				
5	1.0	0.88	0.57	0.8	0.83			0.58				
6	1.0	1.0		1.0	1.0			0.57				
7	1.0	1.0		1.0	1.0			0.57				

show the ratios by sessions. While no regular increase in the size of the ratios is evident there is some tendency for them to increase. In the case of subjects 1, 2, 4, 5 the ratios are 1.00 or nearly so throughout the last three conditioning sessions. This means that the relatively well established conditioned retraction occurred in about the same frequency as the psychophysical judgment.

Subjects 3, 6, 7 made few conditioned responses; instead of becoming established the process broke down completely in the later conditioning sessions. We have no satisfactory explanation for this gross difference in behavior of the two groups. Hull has suggested the possibility that any conditioned response may break down eventually if it does not prove useful in the general adaptation of the organism.¹⁶

Although n is admittedly much too small, it seemed interesting to calculate thresholds from the relative frequencies of psychophysical judgments and the corresponding relative frequencies of conditioned responses. The data from the four subjects who were rather well conditioned throughout the last three condi-

TABLE IX

Absolute visual thresholds calculated from the frequencies of reported light perceptions and from the frequencies of conditioned finger retractions in the test trials of the last three conditioning sessions of subjects 1, 2, 4 and 5

Psychophysical judgment (RL _T)		MEANS			
	1	2	4	5	
Conditioned response (RL _{C-R})	0.0017	0.0015	0.0025	0.0025	0.00205
Psychophysical judgment (RL_T)	0.0025	0.0019	0.0017	0.0025	0.00215
RL _{C-R} /RL _T	0.68	0.79	1.47	1.00	0.953

tioning sessions were used for this final comparison. Table IX gives the threshold values in terms of the photon; the bottom row shows the ratios of the conditioned response visual thresholds to the corresponding psychophysical visual thresholds. These ratios are seen to be somewhere near 1.00 and to distribute themselves around 1.00 with a general mean of 0.953. More data with larger n might lead to the conclusion that the constant and conditioned response techniques can yield comparable threshold values. The technical importance of this matter for comparative psychology is quite evident.

¹⁶ Hull, C. L.: A functional interpretation of the conditioned reflex. *Psychol. Rev.*, 1929, 36, 498-511.

SUMMARY

Under the conditions of the experiment, several rather definite results were secured:

- 1. Visual stimuli of an intensity of the order of 0.005 photon and less were effective in developing conditioned finger retraction and in evoking it when established; thus it appears that extremely low intensities of retinal illumination are conditionable.
- 2. Visual stimuli falling in the range from 3 sigma above to 1 sigma below the 0.5 psychophysical limen were effective in eliciting conditioned finger retractions; in other words, intensities which are around the individual subject's absolute sensory threshold appear to be conditionable. Conceivably, there are many weak repetitive stimuli in everyday life which, without definite recognition, affect behavior by conditioning.
- 3. As indicated in (2), a number of visual stimuli which were subthreshold relative to the 0.5 psychophysical limen evoked conditioned finger retraction; furthermore, in several instances, visual stimuli which were individually reported unperceived had evoked the conditioned response. The probability of artifact seems small, and the conditionability of stimuli below the psychophysical limen seems certain; but the question of whether or not conditioning or conditioned response can occur without consciousness of the conditioned stimulus has not yet been answered with certainty.
- 4. Four subjects became relatively well conditioned during the first four conditioning sessions, and in the remaining three conditioning sessions their frequencies of conditioned response were found to approximate quite closely the corresponding frequencies of reported light perception by the method of constant stimuli. Considering the smallness of n the 0.5 psychophysical thresholds calculated from these pairs of frequencies approximate each other fairly closely. Perhaps subsequent experimentation will verify these indications and establish an interchangeability of conditioned response and psychophysical judgment, as threshold measurement methods. Such a result would be of obvious advantage in comparative psychology.

In the meantime data are limited and results necessarily provisional, but there is in general some evidence for the conclusion that an established conditioned response can be as sensitive an indicator of sensory stimulation as a practiced psychophysical judgment.







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THE ORGANIZATION OF LEARNING AND OTHER TRAITS IN CHICKENS

BY

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Fordham University

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CONTENTS

I. Statement of the problem	1
II. Subjects and tests	
III. Scoring technique and reliability for each test	14
IV. The results	25
V. Summary and conclusions	44
Appendix I. Directional tendency	47
Appendix II. Fitting factor patterns	4 9
Appendix III Citations	55

I. STATEMENT OF THE PROBLEM

This study investigates the organization of traits which underlie chicks' responses to certain simple test situations. The chicks were placed one at a time in each situation and an objective record kept of their responses. Each chick was observed several days in succession in each of the situations. The separate measurements for each test situation were combined into a single score for that situation. The intercorrelations were then determined between these scores. The table of intercorrelations was subjected to tetrad analysis to determine whether the traits underlying the measured performances of the chicks could be satisfactorily analysed into a single general factor plus a specific factor for each test. When such a simple factor pattern was found inadequate, further analysis was carried on to determine what pattern or patterns would account for the intercorrelations.

The situations, which will hereafter be referred to as tests, must be simple if they are to be accomplished by chicks. The

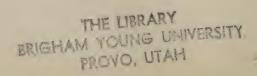
¹ This investigation was partially subsidized by Dr. H. E. Garrett from funds granted by the Council of Research in Social Sciences, Columbia University, for a study of Mental Organization.

nature of these tests must be such that the chick's response or behavior can be readily observed and objectively recorded. This behavior must be reliable, that is consistent from day to day. In addition to the above, the measurements on each test must exhibit variability. A study of the organization of traits requires large populations—Garrett and Anastasi (1932) say one hundred is a minimum population—and at least four but preferably more distinct tests for each individual. The writer has been unable to find published data suitable for an investigation into the organization of traits in animals. In the absence of such data it was necessary to make the measurements or have them made under the immediate observation of the writer.

Some of the tests employed dealt with simple behavior traits such as speed of running, some with learning to escape from problem boxes, one with the number of vocalizations, and one with the consistency of choice of direction, i.e., right or left, in a problem box.

The problem of the organization of abilities at the human level has received wide spread attention during the past three decades, especially the last one. This last period has seen the appearance of two notable works, Spearman's (1927) The Abilities of Man, and Kelley's (1928) Crossroads in the Mind of Man. In addition to these two books there has been a host of monographs, articles, and notes dealing with the experimental aspects of the problem. Still another large body of literature has been developed upon the mathematical problems involved. The mathematics of the problem, are far behind the experimental work; which in fact has been handicapped in its advance by the lack of adequate mathematics.

That the techniques have not been applied to the organization of abilities or traits in sub-human organisms is rather surprising. The use of chicks for experimental subjects allows the investigator to reduce the number and variety of experiences of the subjects. Such variable factors as age, heredity, environment and training are better known and more easily controlled than in the case of human subjects. If group factors are the result of common environmental experiences, their number and probably



their magnitude can be reduced by working with very young chicks. Furthermore, the sheer intricacy of the nervous system in children, adolescents, and adults may necessitate the complex factor patterns found by various workers. The relative simplicity of the nervous system of the chick, especially in the very young chick, may reduce the effects of the complexity of the nervous system on the factor patterns, so that we might expect to find a simple factor pattern sufficient to explain the intercorrelations based on measurements of chicks.

The question immediately arises as to whether an extremely simple pattern such as Spearman's Two-Factor pattern will be found satisfactory to explain the intercorrelations calculated from measurements on young chicks or whether more complicated patterns will be necessary. If group factors appear, to what traits can their origin be traced? Can several different patterns be fitted to the data? If so, which is the more likely pattern? These questions and others must be answered if we would probe into and reveal anything regarding the organization of abilities in animals.

If fairly complex patterns are necessary, and they should happen to be similar in appearance to those required to explain a table of intercorrelations based on human measurements, it cannot be argued that the organization is the same, or that the abilities are the same, but only, that in organisms as far up the phylogenetic scale as the chicken, the sensory motor organization is developed sufficiently to require complex factor patterns for the explanation of intercorrelations derived from measurements on the chicks. It might be expected, as the chicken is relatively far down the scale with regard to man, that the organization would be less complex.

II. SUBJECTS AND TESTS

The subjects²

The subjects used in this experiment were one hundred and nineteen white leghorn chickens. The statistical treatment in

² The writer wishes to acknowledge the courtesy and aid of Dr. D. C. Warren who made it possible to secure the chickens.

the following pages is based on measurements secured on all of these one hundred and nineteen chicks so that the number of individuals is the same for all tables presented. The chickens came from the breeding stock of the Department of Poultry Husbandry, Kansas State College. The eggs from which these chicks were hatched came from one pen so that from the standpoint of blood they are quite homogeneous. The chicks were hatched July 13th and were transferred to the laboratory July 14. The age of the chicks when delivered to the laboratory ranged from twenty-four to thirty-six hours.

Three days were allowed for the chickens to become adjusted to the food, water, physical surrounding and the experimenters. Heterogeneity of the subjects is thus materially reduced with regard to ancestry, age, food, environment and vitality. Evidence pointing to this last factor comes from the fact that at the end of the experiment none of the chicks had died or were ailing.

The diet consisted of a patent chick feed, corn bread, sour milk, green alfalfa, grit, sand, and water. The chicks were fed every three hours during the first ten days. Later cracked wheat and corn were added to the diet and kept constantly in the pens.

The original group of one hundred thirty-nine chicks was divided into two groups. One the experimental group contained one hundred nineteen individuals. The second group, twenty, were used as a stimulus for the other chicks and were called "decoy." The decoy chicks were run through the experiments during the three day period allowed for readjustment. This allowed for the development and smoothing out of various techniques, modification in apparatus and experimental set up and any minor adjustments necessary. The decoy chicks were marked, as a means of ready identification, by coloring the down on the back with purple ink. This was in addition to the wing bands each chick carried. Later whenever the presence of other chicks was required as a stimulus for the chick being tested, these decoy chicks were used. The records of the twenty decoy chicks are not included in the data reported.

³ Chicks that were held in a given area for the purpose of acting as a stimulus to the chick under observation were termed decoys.

On any given day each chick ran three or more experiments. In general the order of the experiments varied from day to day for a particular chick. For example chick A might be the last chicken today and first tomorrow and run the experiments in the order 2, 1, 3, on the first day and in the order 3, 2, 1, the second and in another order the third day. No attempt was made to run the chicks in a serial order through an experiment, or to have the experiments follow a fixed order. It is possible that the giving of the tests in a serial order might generate a group factor; such a factor would be extrinsic and should be excluded from a study of intrinsic factors.

The experiment⁴

Each chick was measured on eleven tests. The number of measurements was the same for all chicks on each test, though the number of measurements varied from test to test. Only one measurement was made on a particular test for a given day, although several different tests might be given on the same day.

For example, see Table I, on July 20, each chick was given one trial in the rotor, T maze, periscope, and the tunnel.

The test situation was presented to each chick individually and a record was kept showing the chick's physical response to the stimuli. The record might be in terms of time to secure a solution, or the distance covered, or the direction chosen, i.e., to the left or right, or of rate.

Two of the tests could be scored in three different ways, time, distance, and rate, thus it is possible to have fifteen sets of scores for each individual. The number of experiments, eleven, together with the number of chicks used made it impossible to measure each chick on all the experiments every day. Table I shows the dates each experiment was carried out. Table I reads, on July 29, all chicks (119) had one trial on each of the following tests, alternate stimulus box, S maze and directional tendency B.

⁴ The administration of so many tests to all the chicks would have been impossible if the writer had not been so ably assisted by Miss Frances Frost and Mrs. Hilda Dunlap.

The tests described below are simple, objective and are fairly reliable. The scores of the chicks show considerable variability on each test. A description of the various methods of scoring, the reliability, and the method of scoring finally adopted is given in Section III.

TABLE I

The dates various tests were given all the 119 chicks

								I	AT	E							
MEASURE	July 1932													Augus			
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2
1. Rotor	*	*	*	*	*	*	*										
2. T. maze	*	*	*	*	*	*	*	*									
3. Periscope	*	*	*	*	*	*	*										
4. Vocalization					*	*	*	*									
5. Tunnel			*	*		*	*	*									
6. Problem box A								*	*	*	*						
7. Problem box B								*	*	•	*	*					
8. Alt. Stim											*	•	•		*	*	
9. S maze													*	*	*	*	4
10. Dirt. tend A								*	*	*	*						
11. Dirt. tend B								*		10	*	10					

The rotors

This device consists essentially of a rotating cylindrical cage, with a platform two inches above the floor of the cage, outside the rotor but immediately adjacent. Electrical contact points were placed on the end of the rotor so as to make five contacts per revolution. Figure 1 shows an end view of this device together with the measurements.

This apparatus was painted a flat black. The floor or covering for the rotor was black galvanized screen wire. The platform was enclosed by screen wire. The contact points were in a circuit with an electric counter. Food was placed on the platform together with four of the decoys. A chick was then placed in

⁵ The writer is indebted to Prof. V. L. Strickland, of Kansas State College, for suggestions and permission to construct this piece of apparatus in the excellent shop of the Psychology Department of Kansas State College.

the cage and the electrical counter cut into the circuit for thirty seconds. At the end of that period a switch was thrown to cut out the counter. Each fifth of a revolution represents approximately five inches of distance covered by the chick in an attempt to get to the platform where the food and other chickens were. The score recorded was the number of revolutions in thirty seconds, recorded in fifths of a revolution.

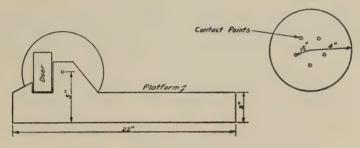


Fig. 1. Rotor

Platform width, 10½ inches. Inside diameter of drum, 5½ inches. Outside diameter of drum, 7½ inches. Counterbalanced door, 2 by 4 inches.

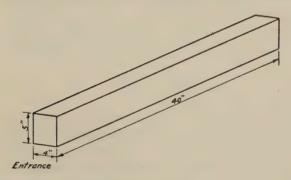


Fig. 2. Tunnel

The tunnel

Figure 2 gives the inside dimensions of the tunnel. This apparatus was painted flat black inside and out. One end opened into a small pen, $8 \times 12 \times 9$ inches covered with screen wire. The other end was closed by means of a slide immediately after the chick was placed in the tunnel.

Four decoy chicks were placed in the end pen to serve as a stimulus. Other stimuli used were food and light. Simultaneously with the closing of the end of the tunnel a stop watch was started. The time, elapsing until the chick's head appeared, when observed from above the opening, was recorded to the nearest fifth of a second and constituted the score.

The S maze

This maze like the tunnel was designed to measure speed, but here other factors enter, namely that the objective is not in view and that the run is broken by right angle turns. Figure 3 gives

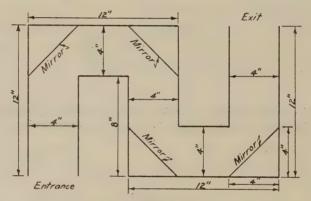


Fig. 3. Periscope Height, 6 inches

the dimensions of the maze. The mirrors were removed and the top was covered with a wire screen during this experiment. The maze was painted flat black. The entrance could be closed by a slide. The exit opened into a box, the floor of which was three inches below the floor of the run so that the chick was forced to jump down in order to join the decoy chicks. This factor did not cause the chicks to hesitate appreciably but it did tend to keep the decoys out of the run.

The stimulus was four chicks in the end pen with food. It is apparent that this was not effective until after one or more trials,

⁶ There seems to be a phototrophism in young chickens so that light acts as a strong stimulant.

depending on the individual chick. The chick was placed in the entrance which was immediately closed and time was kept until his head appeared at the exit viewed from the side. The score was the time, to the nearest fifth of a second, from entering the maze, until the chick jumped down to the end pen.

Vocalization

The apparatus consisted of a box 9 x 12 x 10 inches covered with a wire screen. The chick was first placed for a few minutes in a pen with several other chicks (4 to 8) and then placed alone in the above described box. The stimulus here was the absence of other chicks. Under such conditions most young chicks will emit shrill high pitched cheeps. Each chick was isolated for a period of thirty seconds and the number of cheeps emitted by the chick constituted the score.

The periscope

The apparatus used in this experiment is the same as that used in the S run with the addition of mirrors as indicated in Figure 3. The top was covered with a heavy piece of fiber board painted black in place of the wire screen. The mirrors used were of plate glass three sixteenths of an inch thick and four inches high and five and sixty-six hundredths wide. The last image was not reversed as there was an even number of mirrors. The floor of the end pen was level with the floor of the maze. The stimulus was food and several decoy chicks. The images were so clear and free from distortion that at least four other reflections would have been possible and still have been serviceable for the purpose of this experiment. The score was the time from entering until the chick's head appeared in the exit, when viewed from directly above.

The multiple T maze

The dimensions and layout of the Multiple T maze are given in Figure 4. The left end of each T was closed. The maze was painted a flat black inside and out. The stimulus used was food and the society of other chicks. When a chick succeeded in

solving the problem, he was placed with the other chicks in the main pen and fed, otherwise he was kept alone for five minutes. The chick was allowed five minutes to find his way out of the maze. One score was the time from entering until he found his way out. If after five minutes the chick had not finished, it was removed from the maze for that day. Another score was the

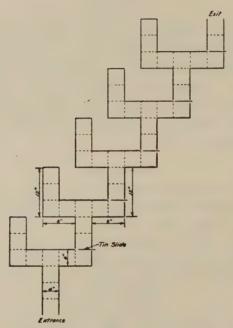


FIG. 4. MULTIPLE T MAZE

Dotted lines indicate units of maze. Height, 6 inches

number of units covered by the chick to the left and to the right in each section of the maze. The dotted lines in Figure 4 indicate the size and location of the units. Still another score was the number of T's covered. Finally a rate score was determined from the distance and time scores.

The alternate stimulus box

The dimensions of the alternate stimulus box are given in Figure 5. The box was so arranged that the mirrors could be

placed at either end and there could be a corresponding reversal of the opaque wall and glass window of the pen. One wall of the pen was of metal painted black, the other was a very clear glass such as used for photographic plates.

Two chicks and food were placed in the small pen. The subject was placed in the entrance of the box. When the chick entered the main body of the box, it was possible for him to see the other chicks eating, due to the arrangement of mirrors. The

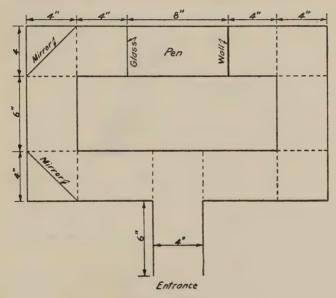


Fig. 5. ALTERNATE STIMULUS Box Height, 6 inches

chick was allowed two minutes to find his way to the glass end of the small pen. In front of this glass was food at which he was allowed to eat for a few seconds, after which he was returned to the main pen. Score was kept on each individual in terms of time, the number of units of distance covered to the right, and the number to the left.

Problem box A

This is a modification of one of Thorndike's (1911) early experiments. The chick is placed in a pen, see Figure 6, the sides and

walls of which are solid while the front is made of black screen wire. The entire apparatus was covered with quarter inch mesh wire screen, except the ramp. A pen of chicks was placed directly in front of the problem box. The subject to be tested was placed at "A," see Figure 6, and allowed five minutes to find its way up the ramp and out. The score was in terms of time. If a chick did not solve the problem it was assigned a score of three hundred seconds.

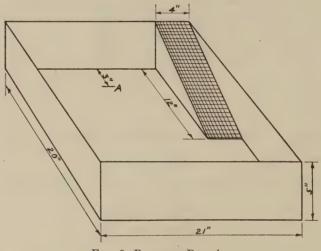


Fig. 6. Problem Box A

Problem box B

This is an adaptation of Kohler's (1925) experiment and like puzzle box A is supposed to measure insight.⁷ The dimensions of the pen are given in Figure 7. The sides were of wood painted a flat black and the front was black screen wire. Directly in front of the problem box was placed a pen enclosing six chicks

⁷ The term "insight" follows Kohler's interpretation of the function used in solving this experiment. This means that in humans the solution would be secured by the process called insight. This does not state that animals will necessarily secure a solution in the same way as a human being. The term insight is a convenient way of designating these measures and will be used throughout this study.

with food. A chick was placed at "A" and time kept to determine how long before the chick could find his way to the pen of decoy chicks. In general, true solutions in the sense of a smooth continuous curve were secured, but many other solutions were apparently just chance. In this, the chicks used here differed greatly from those Kohler used for he reports that a true solution was the exception rather than the rule. Ten minutes were allowed for the solution of the problem, if a chick had not succeeded in this time he was returned to the main holding pen. The score was the number of seconds elapsed until the problem was solved. In the few cases where the solution was not achieved a score of 600 seconds was assigned.

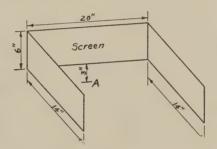


Fig. 7. Problem Box B

Directional tendency

The apparatus used was that for the problem box B. The direction, right or left, that a chick used in solving problem box B was recorded each day. From this material a directional tendency score was derived. The score was the number of times in the five trials that the solution was achieved by going to the right.

This concludes the description of the apparatus used in the experiments reported here.⁸ The experiments while crude, show

⁸ Certain other measures were made but the variation from chick to chick was so slight they were discarded. One of these, an experiment in learning to avoid food that tasted unpleasantly and to inhibit pecks at food which was visible but which the chick was unable to secure offers some promise. It will, however, have to be set up differently to facilitate scoring.

Another measure of directional tendency was secured from the alternate stimu-

considerable variability in responses from individual to individual yet give fairly consistent measures with regard to the variability of a single individual. The reliability of the tests is of such great importance in a study of this nature that a separate chapter will be devoted to it.

III. SCORING TECHNIQUE AND RELIABILITY FOR EACH TEST

The determination of the reliability of each test in this study presents a different problem. The number of trials varied from test to test. Some tests were scored in time, some in terms of total distance covered, some in terms of distance towards the solution and also distance towards a wrong solution and two tests were scored in terms of certain overt mechanical responses to stimuli. The question arises, "How shall the scores of the various trials be combined to bring out most clearly the consistency of the animal's responses and also bring out the variation from individual to individual?" The reliability of each test was determined for each of several different methods of scoring. The method of scoring finally fixed on as the proper one was based on a consideration of the resulting reliability coefficients together with the psychological and logical bases for each particular scoring technique. Generally, this did not result in choosing that method which vielded the highest coefficient although this happened in a few cases.

1. The rotor

Each chick was given seven trials in this apparatus, one on each of seven successive days. The reliability was determined in two ways, first by combining the unweighted scores on trials 1, 3, 5, and 7 into one composite score and the scores on trials 2, 4, and 6 into a second composite score. The correlation between these two was .7383. The correlation was next determined for the sum of the unweighted scores on trials 3, 5, and 7 versus the unweighted sum of trials 2, 4, and 6 with a resulting coefficient of

lus box. This is discussed more fully in Appendix I. The measurement of directional tendency is complicated in this apparatus due to the stimulus from the mirrors to go in a particular direction. For this reason this was not considered in making the factor analysis.

.7374. This stepped up by the Spearman-Brown formula gives .8489 as the reliability of trials 2 to 7 inclusive. The distribution of scores on the first day was not comparable to those of the remaining days so the first scores were discarded. The score used was the average of the last six trials.

2. The tunnel

This apparatus was used to determine how fast a chick could cover a given distance. Each chick was given five trials, one each day. If a chick had not covered the distance at the end of two minutes it was removed from the tunnel. The results of the first day are not included as most of the chicks were quite slow and cautious so that the resulting scores were in no way comparable to those of the following days. The only use made of these first day scores was in fitting curves, as described later, to estimate what a chick would do in terms of the average performance of the decile of which it was a member on the first day. An examination of the records for any individual show that it was able to cover the distance in less than two minutes. Failure to do so can be considered as an error due to factors in the experiment that were not controlled. The score when the distance is not covered in less than two minutes is in no way an estimate of the individual's ability. It is possible to make an estimate of what the individual should make on such a trial and this has been done. The adjusted score, i.e., the score assigned when a chick did not complete the run, was the average score for that trial of those chicks who were in the same decile in trial 1, as the chick being considered. The reliability is reported for these adjusted scores.

The correlation between the scores on trials 2 and 4 with the scores on trials 3 and 5 is .7259, estimating the reliability for all four trials by the Spearman-Brown formula gives .8412. If we adjust the scores on trials 2 to 5 for those individuals who fail to cover the distance in two minutes, and then determine the reliability as above we get respectively .4279 and .5993. This drop is due to the fact that the reliability is a function of the variability of the group and by adjusting the extreme measures we decrease the variability. The reliability as determined from the

unadjusted trials, 3 plus 5, versus 4 was .66 and from the same trials adjusted was .58. None of these measures, however, seem to be satisfactory for it is evident that there has been correlation here between other things than the speed with which the individual covers the distance.

The fastest time recorded for an individual comes nearer to representing his speed than does the slowest time for that individual. This, however, may be subject to error due to some unusual stimulus. A better measure of an individual's speed would seem to be the average of his two fastest trials, regardless of when they were made. In determining the correlation in such a situation there is no reason to take one measure first rather than the other so that it is necessary to double plot the material, the resulting value being the intra-class correlation recommended by Fisher (1925). This correlation was found to be .6435 and the total reliability estimated by the Spearman-Brown formula was .7831. The final measure used as the score for the tunnel was the average score for the two fastest trials, thus eliminating the extreme variability which occurred due to the maximum time limit of two minutes and a minimum time limit of $1\frac{1}{2}$ seconds.

3. The S maze

This maze, like the tunnel, was expected to afford a measure of motor ability in terms of speed. It differed in that the stimuli, food and other chicks, could not be seen at the start, also, that the run was lighted instead of partially dark. An examination of the frequency distribution of scores for each of the six days showed no exceptionally large differences so that the scores for all six days were used.

The correlation was determined for various combinations of the scores on different trials. The reliability was estimated by means of the Spearman-Brown formula, from those correlations. Unweighted scores are used in all the combinations. The correlation between trials 1 and 3, versus the sum of the scores for trials 2 and 4, was .5635, and the estimated reliability coefficient .72. Trials 3 and 5, versus trials 4 and 6, gave the correlation .5055, with a reliability for all 4 trials of .67. The correlation for trials

1, 3, and 5, versus trials 2 and 4, was .6139, with an estimated correlation for trials 1, 3, and 5, versus trials 2 and 4, was .6139, with an estimated correlation of .76. Finally the correlation was determined between the odd numbered trials, 1, 3, and 5, versus the even numbered trials, 2, 4, and 6 as .5902. The reliability for all six trials estimated by the Spearman-Brown was .74. The score finally assigned to each chick was the average score for the six trials with an estimated reliability of .74.

4. Vocalization

In a study investigating the factors underlying a chick's responses it seemed desirable to have a measure that was not primarily a function of motor coördination or of simple learning. When a young chick, that has been raised with others, is isolated it usually emits a high pitched cheep.9 It does not seem that such a reaction would be highly dependent on the motor coördination or on the higher nervous functions.¹⁰ The reliability for vocalization was determined in three ways. First, the six intercorrelations were determined from the scores for the four observation periods, their average taken, and the reliability for all four trials estimated. The reliability was next determined by correlating the combined scores of trials 1 and 3 against those of trials 2 and 4. The resulting correlation was .8276 and the estimated reliability for all four trials was .9057. Finally the correlation was determined between trials 1 and 4 and trials 2 and 3 with a resulting estimated value of .9040. The score finally assigned to each individual was the average score on the four trials with an estimated reliability of .90, the largest value of the three

⁹ Young chicks are quite gregarious and the removal of kind gives a situation similar to humans left alone. This removal of kind causes a disturbance in the chick, which judging from its manifestations is somewhat comparable to the emotion felt by most humans when alone.

¹⁰ It was noted that the chicks tended to cheep in groups of 2, 3, or 4. An occasional chick would emit single cheeps or else cheeps in groups of five. The evidence here is not satisfactory being entirely subjective. This tendency was observed first on the third day of the experiment and was noted again on the fourth and last day. No apparatus was available to determine whether or not there actually is a "rhythm" in the cheeping that is consistent for a particular individual.

coefficients determined. That such a simple measure should have such a high reliability is surprising.

5. The periscope

This experiment was identical with the S maze with the exception that mirrors were set, so that the chick on entering the apparatus could see the end box with the decoy chicks feeding. It is understood of course that this would necessitate that the chick move his head slightly to either side as they have unilateral vision. The results of the first day are not included as a comparison of the frequency distributions of the several days show that it is not typical of the following days. This is due to the fact that the

TABLE II

Correlations resulting from various combinations of scores on the periscope*

VARIABLES	CORRELATION	RELIABILITY BY SPEARMAN- BROWN FORMULA
Σ57 vs. Σ46	.3737	.5441
Σ57 vs. Σ246	.3585	.5278
Σ35 vs. Σ246	.4888	. 6566
Σ357 vs. Σ46	. 4226	. 5941
$\Sigma 357$ vs. $\Sigma 246$. 4752	.6444

^{*} Σ 57 is to be read the sum of the score on trials 5 and 7. Similarly other combinations.

chick on perceiving the movement in the mirror of the decoy chicks would usually start running to join them. The decoy chicks would appear in the mirror as quite a distance away and as a result, the chick would run headlong into the mirror. There would follow a more or less extended period of time while the chick searched vigorously to find a way through this obstacle to the decoys. Then he would notice the reflection of movement in the next mirror and he would dash on to repeat the performance. Occasionally immediately upon running into a mirror he would notice movement in the next mirror and go on to it and attempt to reach the decoy chicks, which were apparently in the mirror. There was considerable variation in learning among the chicks and a particular chick would show considerable variation among his scores from trial to trial.

The scores were combined in various ways, see Table II, to determine just what combination would be best. Table II shows the correlations resulting from the various combinations together with the correlation estimated by the Spearman-Brown formula.

The score finally chosen was the average for trials 2 to 7 inclusive. Study of Table II indicates that the introduction of trial 7 tended to reduce the reliability and this was corroborated by an examination of the distributions of the various days.

6. The multiple T maze

This maze was scored in terms of total time in the maze, in terms of total distance covered, in terms of right (distance to-

	CORRELATIONS	RELIABILITY BY THE SPEAR- MAN-BROWN FORMULA
Total distance $(r + 2w)$, $\Sigma 1357$ vs. $\Sigma 2468$.4282	. 5996
Number of T's completed, Σ1357 vs. Σ2468	.7654	.8672
Distance $(r - w)$, $\Sigma 57$ vs. $\Sigma 46$. 6613	. 7961
Distance $(r - w)$, $\Sigma 1357$ vs. $\Sigma 2468$.7325	.8456
Time, Σ57 vs. Σ46	.7153	.8340
Time, Σ1357 vs. Σ2468		.8906
Ratio of $(r - w)$ score to time, $\Sigma 1357$ vs. $\Sigma 2468$.8636

^{*} $\Sigma 1357$ is to be read the sum of the scores on trials 1, 3, 5, 7. Similarly other combinations.

wards a correct solution) minus wrong distance, in terms of ratio of r-w distance to time, and finally in terms of the number of T's covered. A "T" refers to a single complete T unit of the maze, see Figure 4. The various combinations and the resulting correlations and the reliabilities estimated by the Spearman-Brown formula are given in Table III. The scores involving distance were recorded in terms of the arbitrary units laid off on the floor of the maze. If a chick stepped over the line it was scored a unit right or wrong depending on whether the direction was one that would lead to the correct solution. In the case of total distance the chick was scored one for entering the unit and one when he left a unit if the unit was in error.

There is a possibility of over-refining the scoring unit by breaking it up into fine units. It might be argued that instead of the units used here that the unit should be the number of turns. Due to the way the scores were recorded here it was impossible to adduce any clear evidence on this point. There is, however, evidence that in this case the refinement of scores has somewhat reduced the reliability instead of increasing it as might be expected. The reliability when we score the maze in terms of number of total T's completed gives .87 as against .85 when the T's are broken up into the smaller units and scored, r-w. This difference is not significant statistically nor is the comparison direct, nevertheless it indicates the trend of the material. In this particular problem the introduction of finer scoring units does not seem to have caused a spurious increase in reliability.

Table III gives the reliability coefficients for various combinations of trials of the test, when scored for time, distance (r-w), and rate. The score finally used for this test was the average time for the odd and even trials. There is, however, no evidence at this point to indicate whether the test should be scored in terms of time, distance (r-w) or rate. Evidence for using time rather than one of the other functions is given in Section IV.

7. The alternate stimulus box

The box was so arranged that the mirrors could be set in either end to reflect the decoy chicks together with the food they were eating. The mirrors were set in position to the right or the left of the entrance for the six trials, as follows, R, L, R, R, L, L. It was hoped that such an arrangement of the stimuli would offset any direction tendency due either to habit or genetic forces and that a reliable measure of the accuracy and speed of a chick's response would be obtained. The writer is doubtful of the validity of the test as a measure for anything besides the tendency to turn toward a stimulus and act quickly. Certainly there is very little learning involved. The reliability for this test is not satisfactory.

The determination of the reliability of such a measure offers peculiar difficulties. The usual procedure of taking the odd numbered trials against the even trials is not strictly applicable for if there is a directional tendency in the different individuals, errors in measurement will result due to this tendency. The order of the application of the stimulus would then cause these errors to appear in each of the halves of the test and the reliability would be increased due to the correlation of errors. If, on the other hand, we choose our halves in such a manner as to place in one half only those days when the stimulus was to the right and in the other half only those days when the stimulus was to the left we do not have comparable halves in any except a very broad sense.

This test was scored in terms of total time. Records were kept, also, of the number of units of error and of correct responses made by each individual. These units were entirely arbitrary and were given equal weight in the scoring. The dotted lines in Figure 5 show the size of the various units. The assignment of equal weight to these units is crude. An analogous situation is found in achievement and intelligence tests where all items are assigned the same weight. Various writers in these fields, Ruch and Koerth (1923), Ruch (1924) have shown correlations of .91 to .99 between weighted and unweighted scores. It is possible. however, that in the case of mazes for animals that there would be a significant difference between the reliabilities determined from weighted and unweighted scores. This does not seem likely, though, to the writer. It should be noted that what is an error on the first run of this maze is correct on the second day as it leads to the pen of chicks and food. The reliability as determined by various methods of scoring and combining the scores is given in Table IV.

It was not deemed advisable here to score the task in terms of error, as this would give us a score of resistance to error. Such a score will be positively correlated with the directional tendency, if any, in the chick. It should be noted that in all cases where comparisons can be made between the two methods of combining scores, $\Sigma 135$ versus $\Sigma 245$, and $\Sigma 134$ versus $\Sigma 256$, that the correlation resulting from the latter is smaller. The reason for this is immediately apparent on rewriting the above sums of trials in

terms of the direction of the stimulus, i.e. ΣRRL versus ΣLRL and ΣRRR versus ΣLLL . Such evidence offers indirect support to the arguments presented in Appendix I regarding directional tendency. This method of scoring would tend to generate a group factor between this measure, and the measure of directional tendency, so will be discarded.

Three other possibilities were considered, the score in terms of the difference between the number of units toward a correct solu-

TABLE IV

Correlation coefficients and estimated reliabilities resulting from various methods of scoring the alternate stimulus box*

VARIABLES	CORRELATION	RELIABILITY BY THE SPEAR- MAN-BROWN FORMULA
Distance in units of r - w		
Σ135 vs. Σ246	.4621	. 6321
Σ134 vs. Σ256	.2189	. 3592
$1/2\Sigma 26 + 4 \text{ vs. } \Sigma 35$. 5203	. 6845
Units in error:		
Σ135 vs. Σ246	. 5303	. 6931
Σ134 vs. Σ256	. 1653	.2837
Total distance (r + 2w):		
Σ135 vs. Σ246	.5018	.6682
Σ134 vs. Σ256	.1690	.2891
Total time:		
Σ135 vs. Σ246	.4324	. 6037
Σ134 vs. Σ256	.4068	. 5783
$1/2\Sigma 26 + 4 \text{ vs. } \Sigma 35$. 5079	. 6737

^{*} $\Sigma 135$ is to be read the sum of the scores on trials 1, 3, 5. Similarly other combinations.

tion and those to an incorrect solution; the total distance covered regardless of whether it was toward a correct solution; and lastly time. Total distance covered was eliminated as it is a measure of motor ability. A test should differentiate between the ability of individuals to hit on correct solutions, and such differences can be made to stand out more sharply by scoring in terms of differences rather than sums, when distance is our measure.

The method finally chosen for scoring was half the sum of the

time scores on trials 2 and 6 plus the sum of the time scores on trials 3, 4, and 5.

8. Problem box A

The term insight has been applied to the function measured in this and the next test not because they are necessarily measures of insight but because the term has been used by earlier workers and forms a convenient label. It was expected that these two measures would differentiate chicks with respect to their power to solve problems which require a higher coördination of the nervous organization than do such simple tasks as running a given distance, turning right or left to avoid an obstacle or the emitting of cheeps when placed in solitary confinement. This particular task was very difficult for the chicks and approximately 30 per cent of the scores are undistributed due to failure to solve the problem on any given day. The reliability is somewhat curtailed due to this failure to distribute the scores. The chicks were scored in terms of time taken to get out of the box. The reliability as determined from the correlation between the score on the third and fourth days after applying the Spearman-Brown formula was .6064. When all the data available were used the correlation between the total score on the odd days with the total score on the even days was .6142 and the reliability for the total score for all four trials was estimated to be .7610. It is interesting to note that the reliability estimated for two trials in terms of the correlation between two single days is .6064 and that when we actually work out the reliability between the scores on the odd and even days we get .6142 with a difference that is well within the errors of sampling. This close estimate should increase our confidence in the reliability of the measure. The score used in the determination of the intercorrelations was the average score for the four trials.

9. Problem box B

Ten minutes were allowed for the solution of this problem. If a chick failed he was removed at the end of this period and not given another trial until the next day. Failures to solve the problem were uncommon. Analysis of the failures show that in the 595 attempts, each chick making five attempts, that only 19 failures were recorded. It is apparent from an examination of the original data that ten minutes is sufficient for a solution of the problem and that failure to solve the problem is not due to inability but to some factor that is uncontrolled. Such scores, the 600 seconds assigned in case of failure, are not representative of the individual's ability and should be adjusted in terms of what might be expected, on the average, for an individual with his particular record. Reliabilities are reported both for the unadjusted and adjusted series of scores. The correlation between the unadjusted total score for trials, 2 and 4, with unadjusted total score on trials, 3 and 5, was .4903 and for the adjusted scores .4899. These become, after application of the Spearman-Brown formula, respectively .6580 and .6576. If we take into consideration all the data and include the first trial by taking the average score on trial 1 and trial 5 plus the score on trial 3 against the total score on trials 2 and 4 we get the correlation .4803 for the unadjusted scores and, .5433 for the adjusted scores. Estimating the reliability of the total score from these values we get respectively .6489 and .7041. The final score was computed in terms of the adjusted scores for all five days.

10. A measure of directional tendency

This tendency was measured by noting whether the chick went to the left or right in solving problem box B. The chick could reach the other chicks equally well by turning to the right or left. The direction that the chick chose in reaching a solution was recorded primarily for the purpose of verifying whether or not there was any stimulus not controlled by the experimenter which would cause the chicks to favor either direction. Habits are formed fairly easily by chicks when they have to do with simple functions and it may be that this apparent tendency to right or left is just a result of an easily formed habit. The writer feels that the evidence points more toward an innate tendency. This matter will be discussed in the appendix on directional tendency.

The chick's action was recorded simply as right or left for a

given day. It became necessary to translate these directions into some numerical score in order that the reliability of the chick's action might be determined. The simplest method, perhaps, is to correlate the number of turns to the right on the odd numbered trials against the number of turns to the right on the even numbered trials. This was done with a resulting correlation of .7468.11

IV. THE RESULTS

The reliability of the measures was determined for various scoring methods as described in Section III and the final scoring method chosen after a consideration of the reliability coefficients together with other factors. The scoring of the multiple T maze and the alternate stimulus box gave approximately the same reliability whether scored in terms of time, distance covered in the direction of a correction solution less the distance covered to wrong solutions. or finally, the ratio of distance right minus distance wrong to time. There was no a priori reason for choosing one in preference to the other, so in determining the intercorrelations all three methods of scoring were used for each of these two measures. It was also possible to score the alternate stimulus box in terms of consistency of direction in addition to the methods mentioned above. Thus there are fifteen possible variables, the intercorrelations of which are given in Table V. Care has been taken to adjust the sign in the case of correlations between time and distance. A low time score to cover a given distance indicates speed, and a high score in terms of distance with time constant indicates speed. The correlation between sets of scores measured in this manner would be essentially positive but due to the technique of recording, the resulting coefficient would be negative, obviously an artifact of the method of scoring.

It should be noted that the correlations between variables 1 and 11, 2 and 6, 10 and 11 are negative whereas we would expect them to be positive, these values are all small and the sampling error can well account for their negative sign. There is no reason

¹¹ A somewhat similar coefficient was determined, after allowing for the stimulus from the tendency to turn right or left, on the Alternate Stimulus Box and had a value of .75. See Appendix I.

TABLE V

The intercorrelations and reliability coefficients resulting from the fifteen measures

The subjects were 119 white leghorn chicks. See key below.*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	.849†														
2	200	.783													
3	222	062	.906												
4	277	292	352	. 644											
5	249	198	241	400	.742										
6	120	-023	217	156	121	.761									
7	172	174	092	318	466	331	.704								
8	160	095	217	128	303	147	250	.846							
9	279	181	376	265	383	236	295	825	.891						
10	257	076	341	205	268	143	225	761	867	.864					
11	-018	117	132	073	024	152	076	017	033	-018	.674				
12	124	181	234	207	202	191	211	160	229	191	618	.684			
13	162	196	188	211	093	087	168	105	222	182	434	705	.740		
14	055	090	212	197	116	209	029	031	085	052	052	001	075	.747	
15	181	021	248	102	019	134	-122	016	131	075	-028	016	036	057	.753

- * Key to symbols used in Table V.
- 1. The rotor. The score used was the total number of revolutions recorded in fifths of a revolution for trials 2 to 7 inclusive.
- 2. The tunnel. The score used was the sum of the two lowest times regardless of date made.
- 3. Vocalization. The score recorded was the total number of vocalizations made while isolated on the four trials.
 - 4. The periscope. The score was the total time for trials 2 to 7 inclusive.
 - 5. The S maze. The score recorded was the total time for trials 1 to 6 inclusive.
- 6. Problem box A. The score recorded was the total time for trials 1 to 4 inclusive.
- 7. Problem box B. The score recorded was the time for trials 2, 3, and 4 plus half the time on trials 1 and 5 after corrections were made for erratic values.
- 8. Multiple T maze. The score recorded was the units of success less the units of error for trials 1 to 8 inclusive.
- 9. Multiple T maze. The score recorded was the total time for trials 1 to 8 inclusive.
 - 10. Multiple T maze. This score was found by dividing the score on 8 by 9.
- 11. Alternate stimulus box. The units of success less the units of error for trials 3, 4, and 5 plus half the score for trials 2 plus 6.
 - 12. Alternate stimulus box. The total time for trials combined as above.
 - 13. Alternate stimulus box. The ratio of scores on 11 to 12.
 - 14. Directional tendency. Determined from problem box B experiment.
 - 15. Directional tendency. Determined from the alternate stimulus box.
- † Only the reliability coefficients have decimal points. Decimal points have been omitted for all other correlation coefficients to emphasize the location of the reliability coefficients.

to expect the correlation between the directional tendency scores and the other variables be positive rather than negative. It must be kept clearly in mind, however, that these tests were scored in such a manner that a high score indicates a tendency to go the right and a low score a tendency to go left. Care must be taken to distinguish between those correlations that are negative due to the method of scoring and those that are negative regardless of the technique employed.

It is necessary to eliminate certain measures before we proceed further with this investigation into the organization of factors in the abilities of chicks. It is obvious that if a given measure is scored in terms of time and again in terms of distance that we will introduce a common factor that is outside the chick. Thus we must eliminate two of the three variables 8, 9 and 10 and also two of the three variables 11, 12 and 13 as each set of three represent different ways of scoring the same performance. Consideration of the methods of scoring these and the other tests led to the choice of variables 9 and 12 to represent these two groups of scoring in the final investigation. There are two measures of directional tendency and of these variable 14 was chosen as it was free of any known external stimulus to cause the chick to turn right or left. In view of the argument given in Appendix I it is well to note that the correlation between variables 14 and 15, although small is positive. After correcting the signs, for the nature of the scoring technique used, and eliminating the variables mentioned above, we have as our basic table of correlations. Table VI. This table gives the intercorrelations in the lower left hand corner, the reliabilities down the diagonal, and the correlation coefficients corrected for attenuation¹² in the upper right hand diagonal. It is interesting to note that in this table only one of the correlations is negative. The mean and standard deviation of each variable is given at the bottom of the table.

The remainder of this chapter is devoted to the results of a statistical analysis by means of the tetrad and other correlational functions. This powerful tool in analysis, the tetrad, was de-

¹² The formula for the correction for attenuation as given by Spearman, C. (1904, 1907) is $r = r_{12}/(r_{11} r_{12})\frac{1}{2}$.

TABLE VI

The intercorrelations, are below and to the left of the diagonal, the reliabilities on the upper left to lower right diagonal, the coefficients corrected for attenuation above the diagonal, and the means and standard deviations at the bottom for the ten measures used finally in the investigation of 119 chicks.*

	1	2	3	4	5	6	7	8	9	10
1	.8489†	2411	3135	2534	3749	3210	1629	1488	2218	0694
2	1966	.7831	2601	0734	4111	2167	2479	-0293	2341	1170
3	2489	1983	.7423	2943	5791	4710	2830	1614	6447	1556
4	2222	0618	2413	. 9057	4603	4190	2972	2615	1153	2573
5	2773	2920	4005	3516	. 6444	3502	3120	2229	4724	2833
6	2791	1810	3830	3763	2653	.8906	2928	2869	3723	1043
7	1242	1815	2017	2340	2072	2286	. 6845	2650	3038	0015
8	1196	-0226	1213	2171	1561	2362	1912	. 7610	4525	2778
9	1715	1738	4661	0921	3182	2948	2109	3312	.7041	0394
10	0553	0895	1159	2116	1965	0851	0011	2094	0286	.7468
M	271.2	8.580	195.8	88.08	389.0	1460.	209.4	748.7	382.9	11.12
σ	86.25	4.000	134.4	64.44	196.1	449.9	139.0	285.4	307.0	5.491

- * Key to symbols used in Table VI.
- 1. The rotor. The score used was the total number of revolutions recorded in fifths of a revolution for trials 2 to 7.
- 2. The tunnel. The score used was the sum of the two lowest time scores regardless of the date made.
- 3. The S maze. The score recorded was the total time for trials 1 to 6 inclusive
- 4. Vocalization. The score used was the total number of vocalizations made while isolated on the four trials.
 - 5. Periscope. The score used was the total time for trials 1 to 6 inclusive.
- 6. Multiple T maze. The score recorded was the total time for trials 1 to 8 inclusive.
- 7. Alternative stimulus box. The total time for trials 3, 4, and 5 plus half the time for trials 2 and 6.
- 8. Problem box A. The score recorded was the total time trials 1 to 4 inclusive.
- 9. Problem box B. The score recorded was the time for trials 2, 3, and 4 plus half the time on trials 1 and 5 after corrections were made for erratic values.
 - 10. Directional tendency. Determined from the problem box B experiment.
- † The decimal points have been omitted for all correlation coefficients except those that are reliability coefficients.

vised by Prof. C. Spearman from a consideration of Yule's (1910) theorems on partial correlation.

No attempt will be made here to develop the basic formulae, or in most cases even to state them. These are rather generally known and if not, can be readily found. They are clearly developed by Spearman (1927) and Kelley (1928).

The hypothesis of a general factor plus specific factors

The tetrads resulting from ten variables number 630. To test the significance of the difference of each of the tetrads from zero would necessitate an inordinate amount of labor to determine their individual standard errors. The formula for this as given by Kelley (1928) is

$$\begin{split} \sigma_{t_{1234}} &= 1/N^{\frac{1}{2}}[r_{12}^2 + r_{13}^2 + r_{24}^2 + r_{24}^2 + r_{24}^2 + 2r_{12}r_{14}r_{23}r_{24} + 2r_{13}r_{14}r_{23}r_{24} - 2r_{12}r_{13}r_{23} - 2r_{12}r_{14}r_{24} \\ &- 2r_{13}r_{14}r_{34} - 2r_{23}r_{24}r_{34} + t_{1234}^2\left(r_{12}^2 + r_{13}^2 + r_{14}^2 + r_{23}^2 + r_{24}^2 + r_{34}^2 - 4\right)]^{\frac{1}{2}} \end{split}$$

Cureton and Dunlap (1930) give an approximation formula by which we may estimate the probable error for any tetrad in the table picked at random thus relieving us of the necessity of determining the individual probable error for each of the six hundred thirty tetrads.

$$\sigma_{t_4} = 2/N^{\frac{1}{2}} [r'^2(1-r')^2 + S^2 - (\Sigma t_4^2/_{3n}C_4)(1-1.5R^2)]^{\frac{1}{2}} *$$

* t_4 = the random tetrad.

N = the total frequency.

n =the number of variables.

 3_nC_4 = the number of tetrads.

r' = the average intercorrelation between variables.

 R^2 = the average of the squares of the intercorrelations.

 S^2 = the mean square variation of the intercorrelation from their mean, so that $S^2 = R^2 - r'^2$.

The probable error of a tetrad chosen at random is of the magnitude .022. It will be noted in Figure 8 that the tetrads are so distributed about zero (the mean for the entire table, carried to 2 places, is zero) that approximately the correct proportions are in each category so it may be assumed that the distribution is normal. The distribution has been double plotted, each tetrad being recorded once as positive and once negative, as the sign is dependent on the order chosen for the variable. The fact that some of the tetrads are quite large leads one to inquire if, perhaps, instead of these large tetrads being random variations, a closer examination might reveal that a certain group of variables were

responsible for the greater portion of these. If this situation holds it would be revealed by an examination of finer subdivisions such as the directed mean tetrads, 13 t_{12ij} , t_{13ij} , etc. If certain of the directed mean tetrads differ considerably from zero a more complex factor pattern than a single general factor plus specific factors might be postulated as underlying the correlation table.

That this procedure is reasonable is at once apparent, for if we had, say a twenty variable problem in which a general factor runs

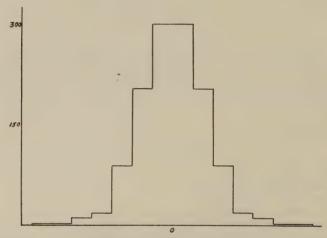


Fig. 8. Distribution of 630 Tetrads Calculated from Raw Correlations in Table VI

Each tetrad plotted once as positive and once as negative. The interval used was 1 P.E. of the mean tetrad.

through all the variables, a group factor through two variables, plus specific factors for each variable then there would result 12,920 tetrads, in 306 of which there would be evidence of a group factor. These 306 tetrads represent only 2.4 per cent of the total and would be regarded as relatively unimportant in

¹³ The term "directed mean tetrad" is used to designate the average or mean of all the tetrads in which a particular pair of variables always appear together, such as say t_{12ij} , t_{13ij} , etc. The expression t_{12ij} in a five variable problem is the average of the following tetrads; t_{1234} , t_{1243} , t_{1235} , t_{1253} , t_{1254} . This is different from the mean tetrad of the table of tetrads.

such an analysis as carried out above, especially if the group factor was small. A distribution table of the tetrads instead of indicating the likelihood of a group factor would tend to obscure its presence so that it might be easily overlooked. Thus it is advisable before making any conclusions to examine the directed mean tetrads.

The directed mean tetrads are presented in Table VII.¹⁴ There are forty-five such tetrads¹⁵ each with a probable error of the gen-

¹⁴ The directed mean tetrads can be readily calculated directly from the table of correlations by means of the following formula. This formula is a modification of the technique presented by Broyler (1932) and is directly adapted for purposes of machine computation.

$$t_{\overline{ab}ij} = \left[r_{ab} \left(\sum_{\substack{i=1\\i=1}}^{n} r_{ij} + r_{ab} - \sum_{\substack{i=1\\i=1}}^{n} r_{ai} - \sum_{\substack{i=1\\i=1}}^{n} r_{bi} \right) + \sum_{\substack{i=1\\i=1}}^{n} r_{ai}r_{bi} - \sum_{\substack{i=1\\i=1}}^{n} r_{ai} \sum_{\substack{i=1\\i=1}}^{n} r_{bi} \right] / (n-2) (n-3)$$

where $i \neq j$; $a \neq i$; $b \neq i$; and the summation is over the entire table of correlations, not half the table as is usually written. The major diagonal is fitted with ciphers. It is necessary to sum the columns and write the values in as shown in Table A.

3 1 5 Σij 1 0 .20.25 .22 .28 .20 2 .20 0 .06 .29 3 .25 .20 0 .24 .40 4 .22 .06 .24 0 .35 5 .28 .29 .40 .35 0 1.09 .87 1.32 4.98 $\sum r_{ai}$.95 .75

Table A.—Intercorrelations

The only term that may cause difficulty is $\Sigma r_{ai} r_{bi}$. This, however, is simple, for in the tetrad $t_{\overline{13}ij}$ it consists of the sum of the products of .20 × .20; .22, × .24; .28 × .40. The set up for machine calculation is obvious after a moments inspection of the formula and the relative magnitude of the different terms. Once the computation starts the values are always in the machine.

¹⁵ It is necessary to know the standard deviation of a directed mean tetrad before it can be of any great value. The formula for this together with its derivation was given by Dunlap (1931). The formula is given below.

$$\begin{split} \sigma_{t_{12}} &= [1/(n-2)\ (n-3)]\ [2r_{12}^2\sigma^2 + 2(n-3)\ r_{1}^2\sigma^2 + (n-2)\ (n-3)\ r^2\sigma^2 + 4\\ &\quad (n-4)\ r_{12}^2q + (n-4)\ (n-5)\ r_{12}^2p - 8\ (n-3)\ r_{12}r_{1q} - 4\ (n-3)\ (n-3)\ (n-4)\ r\ _{12}r_{1p} + 2\ (n-2)\ (n-3)\ r_{12}r_{p} + 2\ (n-2)\ (n-3)\ r_{1q}^2q + 2\ (n-3)^2r_{1p}^2 - 4\ (n-2)\ (n-3)\ r_{1q}]^{\frac{1}{2}} \end{split}$$

eral magnitude of .01. Five of the directed mean tetrads are greater than three times their P.E. This number is more than twice what we would expect if the size of the directed mean tetrads was entirely a matter of chance, or if they were entirely attributable to the simpler pattern of one general factor plus specifics. This is perhaps unfortunate, for the determination of more complex patterns is not only more difficult to determine numerically but more hazardous to defend.

It is true that none of the directed mean tetrads exceed 4.1 times their probable error and it may be argued that none of these differences are significant. If only one such deviation of three times, or four times, or even five or six times the probable error had occurred it could and should be viewed with suspicion. Where, however, we have not one but five cases where the value exceeds its standard error by three times the probable error, some significance should be attached to the fact. In view of this evidence it seemed advisable to consider other explanations than that of a single factor plus specifics, so the following patterns were fitted.

It will be apparent from the following work that a large number of equally good fits can be made. The question now resolves itself into which of the patterns or family of patterns, for there seems to be a tendency for the patterns to fall into groups, shall be chosen. The law of parsimony offers a starting point. In the following pages various patterns fitted to the data are presented.

```
Where r_{12} is the correlation between x_1 and x_2
```

$$r = 2\Sigma (r_{ij}) / (n-2) (n-3)$$

 σ^2 is the mean variance of the correlation coefficients

$$\sigma^2 = (1 - R^2)^2 / N$$

$$R = (r_{12} + 2r_1 + r)/4$$

$$q = \frac{1}{2}N\left[2r_{23}\left(1-r_{12}^2\right)\left(1-r_{13}^2\right)-r_{12}r_{13}\left(1-r_{12}^2-r_{13}^2-r_{13}^2+2r_{12}r_{13}r_{23}\right)\right]$$

 r_1 is the mean correlation between x_1 and any variable not x_2 , and of that between x_2 and any variable not x_1 , i.e., $r_1 = \sum (r_{1i} + r_{2i})/2$ (n-2)

r is the mean correlation between two variables neither of which is x_1 , or x_2 , i.e.

 $p = [r_{13}r_{24} + r_{14}r_{23} - (r_{12}r_{13}r_{14} + r_{12}r_{23}r_{24} + r_{13}r_{23}r_{24} + r_{14}r_{24}r_{34}) + (r_{12}r_{34}/2)$ $(r_{13}^2 + r_{14}^2 + r_{23}^2 + r_{24}^2)]/N$

n =the number of variables

N =The population

The tetrads were calculated from the values given in Table VI for the uncorrected coefficients. The 630 individual tetrads possible from ten variables are not given here. Table VII gives the directed mean tetrad for each pair of variables. An examination of the two hundred ten triplets of tetrads revealed that only ten are sufficiently close to zero that the correlations underlying them may be readily thought of as being due to one general factor and four specific factors. Thus the evidence from an examina-

	1	2	3	4	5	6	7	8	9
1									
2	.018								
3	.001	.002							
4	.005	026	015						
5	.005	.024	.005	.009					
6	.010	002	.007	.021	026				
7	008	.016	007	.012	008	.002			
8	010	039	027	.008	021	.004	.013		
9	010	.002	.039	042	002	002	.004	.036	
10	011	.004	- .006	.027	.014	- .013	025	.035	025

^{*} This table is read as follows: The directed mean tetrad t_{13} is found in column 1, row 3, and has the numerical value .001.

tion of the table of individual tetrads is in general against the two factor hypothesis.

It is necessary now to fit patterns to the data which will give a reasonable explanation of the correlations in Table VI. Four patterns have been fitted to the data. The first pattern was fitted using the correlation coefficients in Table VI to three figures, the other 3 factor patterns were fitted keeping the correlations to two places. The patterns fitted use respectively 8, 7, 6, and 4 factors in addition to specific chance and specific nonchance factors. An examination of either of the four tables show that in no case have the number of coefficients assigned to the various factors approached the limit imposed by our conditions.

In Table VIII we have used eight factors with a total of 34 coefficients, or 44 when the specific nonchance factors are included to explain the intercorrelations found in Table VI. This is well within the imposed limit of 55 coefficients. The mean value of differences for the observed correlations and the correlations estimated from the coefficients assigned in the eight factor pattern is .002 and the standard deviation of these differences is .022. The condition imposed by formula 5 (see Appendix II) is met closely as we get the value of 0.13 as the difference. This difference is small with relation to the magnitude of the original

TABLE VIII

Factor pattern using 8 factors plus specifics showing location and values assigned the bonds and specific factors*

	U_1	U_2	U_{3}	U_4	$U_{\mathfrak{b}}$	U_6	U_7	U_8	s_i	S_c
1	.32	.50	.20						. 673	.389
2	. 39	.17			22		49		. 560	. 466
3	. 41	.20	.25					.68	.095	. 508
4	. 64		.09	.43			.38		.399	.307
5	. 58	.20			08	.16		.20	.442	. 597
6	. 51		. 58						.543	. 330
7	. 43					28			.649	. 561
8	. 37				.76				.216	.489
9	. 53			55	.16			.30	.071	. 544
10	.24			.18	.15	.37			.705	. 503

^{*} The values for the various U's were determined to three places, and for the S's to four places. The checks were applied to those values and the values later rounded to appear as above. Similarly in Tables X, XII and XIV.

values (28.45) and indicates that the fit is close. Table IX shows the observed correlations, the estimated correlation calculated from Table VIII and the difference between the two. The maximum difference is .047 which is well within .06, the probable error for the value of the mean correlation of the table, namely, .205.

Table X shows the allocation of coefficients and their magnitude when we use seven factors to explain the intercorrelations of Table VI. Table XI gives the original coefficients to two places, the estimated values, and their differences. Only 43 coefficients were used in fitting the pattern in Table X again well within the

TABLE IX

Showing the observed values, the estimated values based on bonds in Table VIII and the differences as evidence of closeness of fit*

r	OBV. VALUE	EST. VALUE	DIFF.	*	OBV. VALUE	EST. VALUE	DIFF.	r	OBV. VALUE	EST. VALUE	DIFF.
12	.197	.210	013	29	.174	.172	.002	56	.265	.296	031
13	.249	.281	032	2x	.090	.061	.029	57	.207	.205	.002
14	.222	.222	.000	34	.241	.284	043	58	.156	.164	008
15	.277	.285	008	35	.401	.414	013	59	.318	.355	037
16	.279	.279	.000	36	.383	.354	.029	5x	.197	.188	.009
17	.124	. 137	013	37	.202	.176	.026	67	.229	.219	.010
18	.120	.118	.002	38	.121	.152	031	68	.236	. 189	.047
19	.172	.169	.003	39	. 466	.424	.042	69	.295	.270	.025
1x†	.055	.076	021	3x	.112	.099	.013	6x	.085	.122	037
23	.198	. 194	.004	45	.352	.370	018	78	.191	.159	.032
24	.062	.064	002	- 46	.376	.378	002	79	.211	.208	.003
25	.292	.278	.014	47	.234	.275	041	7 <i>x</i>	.001	006	.007
26	. 181	. 199	018	48	.217	.237	020	89	.331	.317	.014
27	.182	.168	.014	49	.092	. 103	011	8 <i>x</i>	.209	.203	.006
28	- .023	023	.000	4x	.212	.231	019	9x	.029	.052	023
				J]	J .	J		

^{*} The correlation between two variables is due to their common bonds. Thus to estimate r_{12} from Table VIII, multiply the common coefficients under U_1 , .32 × .39 = .1248, then under U_2 , multiply .50 × .17 = .0850. There are no other common bonds, S_i and S_c being specifics, the first inherent to the measure, the second S_c due to unreliability or chance. The sum of the products of common bonds is, thus, here .1248 + .0850 = .210 to three places. Similarly the estimated value r_{59} equal $(U_1$, .58 × .53 = .3074) + $(U_5$, -.08 × .16 = -.0128) + $(U_8$, .20 × .30 = .0600) = .355.

TABLE X

Factor pattern using 7 factors plus specifics showing the location and values assigned the bonds and specific factors

	U_1	U_2	U_3	U_4	U_5	U_6	U_7	S_i	S_c
1	.40			.17				.812	.389
2	.40			.20	.15	30		. 686	.466
3	.54	. 50			.16			.418	.508
4	. 49	10	.20			.40		. 675	.307
5	. 56	.15	.20	.30			30	.296	. 597
6	.60	.11				.20	.30	. 623	.330
7	.43		10					.700	. 561
8	.45		.20	35	60			. 190	.489
9	.38	. 55			20			. 466	. 544
10	.17		.60					. 598	. 503

[†] The letter x represents variable ten.

limit, 55. The closeness of the fit is apparent from the following facts. The mean of the differences between the observed and the estimated correlations was .002 and the standard deviation of these differences was .028. Applying formula 5 we find a difference of only .017 for the entire table. The condition imposed by formula 4 (Appendix II) is met by all the variables. Finally the maximum difference between the estimated and observed coefficients is .053 whereas the probable error for the mean correlation, as pointed out above, is .06.

TABLE XI Showing the observed values, the estimated values based on the bonds in Table X and the differences as evidence of closeness of fit

r	OBV. VALUE	EST. VALUE	DIFF.	r	OBV. VALUE	EST, VALUE	DIFF.	r	OBV. VALUE	EST. VALUE	DIFF.
12	. 197	.194	.003	29	.174	.122	.052	56	.265	.262	.003
13	.249	.216	.033	2x	.090	.068	.022	57	.207	.221	014
14	.222	. 196	.016	34	.241	.215	.026	58	.156	.187	031
15	.277	.275	.002	35	.401	.377	.024	59	.318	.295	.023
16	.279	.240	.039	36	.383	.379	.004	5x	. 197	.215	018
17	.124	.172	048	37	.202	.232	030	67	.229	.258	029
18	. 120	.120	.000	38	.121	.147	026	68	.236	.270	034
19	.172	.152	.020	39	.466	.448	.018	69	.295	.288	.007
$1x^*$.055	.068	013	3x	.112	.092	.020	6x	.085	.102	017
2-3	. 198	.240	042	45	.352	.299	.053	78	. 191	.174	.017
24	.062	.076	014	46	.376	.362	.014	79	.211	.163	.048
25	.292	.284	.008	47	.234	. 191	.043	7 <i>x</i>	.001	.013	012
26	.181	.180	.001	48	.217	.260	043	89	.331	.291	.040
27	.182	.172	.010	49	.092	.131	039	8 <i>x</i>	.209	.196	.013
28	023	.020	043	4 <i>x</i>	.212	.203	.009	9x	.029	.065	036
				1		,		1	·		

^{*} The letter x represents variable ten.

The next pattern fitted uses only six factors and 40 coefficients to explain the intercorrelations in Table VI. This pattern and the coefficients meet all the conditions imposed. The sum of the squares of the coefficients for each row sum to unity. The mean of the differences as shown in Table XIII is .009 and the standard deviation is .03. The difference between the two values determined by formula 5 is larger than in the previous patterns being 0.48, this is, however, still small when compared with the total value, 28.45.

TABLE XII

Factor pattern using 6 factors plus specifics showing the location and values assigned the bonds and specific factors

	U_1	U_2	U_8	U_4	U_{δ}	U_6	s_i	S_c
1	.38		.15			Manager 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	.82	.390
2	.40				.30	.30	. 66	.470
3	. 50		. 60		. 10	. 10	.33	.510
4	. 60	.40		30	,	- . 50	.21	.310
5	. 62	30	. 15		. 15		.34	. 600
6	. 50	. 10	.25				.75	. 330
7	.35			.10			.74	. 560
8	.41				60		.48	. 490
9	.45		.35	. 60			.12	. 545
10	.25			15	15		.80	. 500

TABLE XIII

Showing the observed values, the estimated values based on the bonds in Table XII, and the differences as evidence of closeness of fit

r	OBV. VALUE	EST. VALUE	DIFF.	r	OBV. VALUE	EST. VALUE	DIFF.	r	OBV. VALUE	EST. VALUE	DIFF.
12	.20	.15	.05	29	. 17	.18	01	56	.27	.32	05
13	.25	.28	03	2x	.09	.06	.03	57	.21	.22	01
14	.22	.23	01	34	.24	.25	01	58	.16	.16	.00
15	.28	.26	.02	35	.40	.42	02	59	.32	.33	.01
16	.28	.23	.05	36	.38	.40	02	5x	.20	.14	.06
17	.12	. 13	01	37	.20	.18	.02	67	.23	.18	.05
18	.12	.16	04	38	.12	.14	02	68	.24	.21	.03
19	.17	.22	05	39	.47	.44	.03	69	.30	.31	01
$1x^*$.06	. 10	04	3x	. 11	.11	.00	6x	.09	.12	03
23	.20	.26	06	45	.25	.25	.00	78	. 19	.14	.05
24	.06	.09	03	46	.38	.34	.04	79	.21	.22	- 01
25	.29	.29	.00	47	.23	.18	.05	7 <i>x</i>	.00	.07	07
26	.18	.20	02	48	.22	.25	03	89	.23	.18	.05
27	.18	.14	.04	49	.09	.09	.00	8 <i>x</i>	.21	. 19	.02
28	02	02	.00	4 <i>x</i>	.21	.20	.01	9x	.03	.02	.01

^{*} The letter x represents variable ten.

The last two patterns have been fitted using correlation coefficients only to two places as the writer feels that the fit obtained from any particular pattern can be considered only as an approximation. Extreme accuracy in the results is superficial, and may

lead the reader to a feeling of security with regard to the results which has no real justification. Further, the allocation of the coefficients shift somewhat and the number of factors vary from pattern to pattern. An examination of the three patterns may indicate some factors which appear consistently and in which the magnitudes of the coefficients assigned to different variables shift slightly. If such factors can be found on inspection they may represent some real, rather than apparent, underlying factors or abilities. It should be kept in mind, however, that these factors may be due in part to the similarity existing among the

TABLE XIV

A factor pattern using 4 factors plus specifics showing the location and values assigned the bonds and specific factors

	U_1	U_2	U_3	U_4	S_i	S_c
1	.42				.82	.39
2	.38		.72		.35	.47
3	. 57	.34			. 55	. 51
4	. 53	- . 19	19		.75	.30
5	. 65				.47	. 60
6	.61				.72	. 33
7	.40				.72	. 57
8 .	.34		21	.73	.26	. 49
9	.42	. 67		.26	.00	. 55
\boldsymbol{x}	. 20			. 19	.82	. 50

hypotheses set up with regard to the relationships existing among the variables. Such a combination of patterns has been made and is given in Table XVI.

Dr. C. Spearman has suggested to the writer that patterns fitted as closely as the preceding ones were "over fitted," that is, they were fitted closer than the errors in the original correlation coefficients justify. A result of such closeness of fit is that an undue number of factors are necessary to explain the coefficients. The following pattern has been constructed with this in mind and no attempt made to fit the correlations closer than one standard deviation. In only two cases does the difference between the observed and estimated correlation exceed one standard deviation.

The resulting pattern is given in Table XIV. A closer fit than that exhibited in Table XV probably is not warranted. It should be noted that for the general factors the weights assigned are approximately the same in all four patterns. The group factors in the four factor set-up present a quite different picture from the other patterns.

The coefficients assigned to the general factor for each of the variables in the four patterns are substantially the same, with the

TABLE XV

Showing the observed values, the estimated values based on the bonds in Table XIV and the differences as evidence of the closeness of fit

r	OBV. VALUE	EST. VALUE	DIFF.	r	OBV. VALUE	EST.	DIFF.	r	OBV. VALUE	EST.	DIFF.
12	.20	.16	.04	29	.17	.16	.01	56	.27	.40	13
13	.25	.24	.01	2x	.09	.18	09	57	.21	.26	05
14	.22	.22	.00	34	.24	.30	06	58	.16	.22	06
15	.28	.27	.01	35	.40	.37	.03	59	.32	.27	.05
16	.28	.26	.02	36	.38	.35	.03	5x	.20	.13	.07
17	.12	. 17	05	37	.20	.23	03	67	.23	.24	01
18	.12	. 14	02	38	. 12	.19	- . 07	68	.24	.21	.03
19	.17	. 18	01	39	.47	.47	.00	69	.29	.26	.03
$1x\dagger$.06	.08	02	3x	.11	.11	.00	6x	.09	.12	03
23	.20	.22	02	45	.35	.34	.01	78	. 19	.14	.05
24	.06	.06	.00	46	.38	.32	.06	79	.21	.17	.04
25	.29	.25	.04	47	.23	.21	.02	7 <i>x</i>	.00	.08	08
26	.18	.23	05	48	.22	.22	.00	89	.33	.33	.00
27	.18	.15	.03	49	.09	.09	.00	8 <i>x</i>	.21	.21	.00
28	02	02	.00	4 <i>x</i>	.21	.11	. 10	9x	.03	. 13	10

^{*} The letter x represents variable ten.

exception of variable 9 and possibly variables 3 and 4. If we set as the criterion, that the difference may be no greater than twenty-five per cent of the largest value then all of the weights assigned the general factor are in substantial agreement.

Interpretation of patterns

It has been shown that several patterns can be fitted to the same body of data, but there still remains the problem of interpretation of just which physiological or psychological entities are responsible for these patterns. The first step was to take the first three patterns and examine them for common elements. Table XVI presents a pattern in which all elements that are common to each of the three patterns are shown with a rough indication of their magnitude.

The giving of names to the functions represented by the six factors is highly subjective and therefore susceptible to differences of opinion with their resulting disputes. The writer shall venture, however, to give names to these factors, for before a

TABLE XVI

A factor pattern exhibiting the characteristics common to 3 patterns (Tables VIII, X and XII) fitted to a table of intercorrelations derived from ten sets of measurements on 119 chickens*

	<i>U</i> . ₁	U_2	U ₃	U_4	U_{δ}	U ₆
1	+	+8				
2 3	+	+L		+S +L	-S -S +L	
4 5	+ +	+L	+L	. +L	+L	+8
6	+			·		+8
8	+			-L		
9 10	+ +		-L +S			

^{*} S and L refer respectively to large and small coefficients, the appropriate sign being prefixed.

hypothesis can be tested it must be recognized and should be stated.

The general factor U_1 may be a function of either general motor skills or a function of general nervous activity. The latter seems more probable, for two of the measures, vocalization and directional tendency are nearly free of nervous ability. Obviously all of the measures are, however, dependent on sensory and nervous activity. The five group factors shown in Table XVI are consistent in the three patterns. What these factors are can not be determined but an examination of the tests may throw some light on their nature.

The factor U_2 in Table XVI shows bonds between variables 1, 3, and 5. The coefficient for variable 1 is rather small whereas that for variables 3 and 5 is large especially the coefficient for variable 3. Something of motor ability is called for in running the rotor if the chicken is to save himself from bad falls. Likewise in the case of the periscope the chicken is likely to run into the mirrors with considerable force at first. The resulting efforts, later, to keep from touching the mirror, call forth a higher order of muscular activity than ordinarily used. The bond between variables 3 and 5 is due to the close relationship between the two measures. Further as this test (variable 3) was given after variable 5, the habits developed may have carried over to a certain extent.

Factor U_3 shows a bond between variables 4, 9 and 10. The coefficients for variables 4 and 9 are large while that for variable 10 is small. The coefficient for variable 9 has a negative sign, indicating that while this factor tends to give high scores for variables 4 and 10 (vocalization and direction tendency) it also tends to reduce the score for problem box B. Vocalization, variable 4, and directional tendency, variable 10 may be prepotent tendencies to act in a given way without regard to circumstances. This prepotent tendency to act would be positively correlated in variables 4 and 10 but would correlate negatively with variable 9 where undirected activity tends to reduce the score.

The factor U_4 shows a bond between variables 2, 3, 5, and 8. The sign of the coefficient for variable 8 is negative so that the factor for this variable reduces the score or rather as the score is in terms of time, increases the time necessary for the chick to arrive at a solution. Variables 2, 3, and 5, the tunnel, the S maze, and the periscope require very low order of nervous organization for their solution as compared with problem box A. This last is by far the most difficult of solution of the tests used. An essential factor in the solution of variables 2, 3, and 5 is the speed with which the chick covers the distance, but this factor, speed, in running back and forth across the front of the enclosure in problem box A decreases the chick's chance of noticing the inclined runway that gives the solution of the problem. It

would seem that the common factor here is speed which acts in a deterrent or negative fashion in variable 8.

In the factor U_5 there appears but small coefficients for variables 2, and 3, the tunnel and the S maze, and a large positive coefficient for variable 4, vocalization. The vocalization of a chick may indicate an emotional disturbance resulting from changes in glandular secretions caused by the lack of the presence of other chicks. This disturbance may tend to inhibit physical efficiency and thus reduce the score on those variables which are primarily motor, such as the tunnel and the S maze. It should be noted that the coefficients for variables 2 and 3 are small indicating that the inhibitory effect is small. It is probable that the effect is felt by the other variables but that the reduction in efficiency is so small that it is not necessary to indicate the coefficients in obtaining a satisfactory fit.

It is possible to reverse all the signs for a particular factor or an entire table without affecting the resulting correlation coefficients. The choice of signs is left to the judgment of the worker, and should be determined by an examination of the measures. Reversing the signs in the factors U_5 reduces considerably whatever efficacy the above explanation may possess, in fact an interpretation is not at all obvious after such a reversal.

The last factor U_6 shows a small but consistently positive bond between variables 4 and 6, vocalization and the multiple maze. No reasonable explanation for this bond occurs to the writer. It can be argued in the case of certain of the factors that the bonds are due to similarity of content of the variables, for example the S maze and mirror run, the path being identical, or in problem box A and problem box B where both require for their solution a reversal of direction of 180 degrees. It is difficult to see how the above factor, U_6 , can be explained on the grounds of similarity of content.

An interpretation of the four factor pattern

The general factor U_1 may be interpreted as above, namely general nervous activity. The factor U_2 might be interpreted as the ability of the chick to recognize the spatial relationship of

itself with regard to the entire situation. The negative sign in 4 substantiates this for such a factor tends to reduce the score, here the number of cheeps. The cheeps are a rough measure of the inability of the chick to realize the proximity and location of others.

The factor U_3 may be considered as speed in muscular activity which is positive for the tunnel and negative for the two variables, vocalization and problem box A. Sheer speed tends to be a "good" in the case of the tunnel, but in the case of the problem box A speed in running back and forth may cause the chick to overlook the ramp. In vocalization the chick rarely cheeps when engaged in any other overt physical activity.

The factor U_4 appears in the three variables, problem box A, problem box B, and directional tendency. This last variable was secured from the consistency of the chick's action in the problem box B. This factor might be designated, dextral tendency. The chick that has a tendency to go right has better opportunity of locating the ramp and solving the problem in problem box A. Tendency to go right is also of value in problem box B, but no more so than a sinstral tendency. Finally such a tendency would be expected to appear in variable 10, direction tendency.

It is apparent to the reader that the above interpretations of the factor patterns are subjective and that with thought regarding the form of the test, the scoring, and the performance of the chicks other plausible interpretations could be given. The various patterns together with interpretations have been given in order to emphasize the fact that a given table of intercorrelations can be reproduced from any one of several factor patterns each having a different interpretation. The final choice of a pattern would seem to be dictated by the law of parsimony and by the reasonableness of the faculties, or powers, or abilities assigned to the various factors when interpreting the factor pattern. The writer does not believe that, necessarily, anyone of the above patterns is the right or best or true pattern.

It should be clearly understood that the factors in the various factor patterns presented are not to be considered as psychological realities, or existences, or ultimates, but only as decimal multi-

pliers which in a given pattern are useful in explaining a given system of correlation coefficients. Thus the interpretation of the patterns is nothing more or less than postulates which are made in order that these relationships may be thought of in the common symbolic form, language. The mathematics of the problem may be correct, and a pattern presented be unique, but that in itself is no guarantee of the validity of the interpretation. The body of evidence does, however, seem to indicate that the intercorrelations presented in Table VI cannot necessarily be thought of as due to one general factor plus specific factors. Just where the group factors should appear and to what they are ascribable will necessarily await further investigation, both mathematical and experimental.

It may be, that all the preceding work is wasted as the magnitude of the original coefficients is so small. Only future investigations with better devised tasks, more refined laboratory techniques, and methods for recording observations, together with larger number of cases can evaluate this study. The very fact that such investigations are made will justify this one.

V. SUMMARY AND CONCLUSIONS

Summary

- 1. Measurements were made on one hundred nineteen chicks, highly homogeneous as to ancestry, age, vitality, and physical environment in controlled experimental situations.
- 2. Eleven types of activity were recorded for each chick in terms of a numerical score. Certain of the activities were primarily motor, others required the functioning of a higher degree of nervous organization than simple motor activity. Two of the tests were each recorded or scored in three ways so that fifteen variables were reported in Table V.
- 3. The reliabilities of the different tests were determined for various methods of scoring. These scoring techniques are reported and reasons presented for choosing the particular scoring method finally used.
 - 4. Ten variables were selected for the final study. The means,

standard deviations, intercorrelations, reliability coefficients, and correlations corrected for attenuation are given.

- 5. The tetrads resulting from the correlation coefficients uncorrected for attenuation were calculated, and an examination of the triplets of tetrads made. In seemed advisable after this examination to fit various factor patterns, to determine which set of decimal multipliers would best explain the facts.
- 6. Various patterns are presented and an interpretation attached to two of the patterns.
- 7. The technique used in fitting the factor patterns is described in Appendix II.
- 8. Formulas are given for determining the directed mean tetrad and its standard error directly from the table of intercorrelations.

Conclusions

- 1. The evidence presented indicates that the table of intercorrelations based on ten different tests each on 119 chicks cannot be satisfactorily explained by one general factor plus specific factors.
- 2. Four factor patterns were fitted to the data, one using eight factors, one using seven factors, one using six factors, and the last using four factors.
- 3. A general factor pattern using six factors was derived from a consideration of the first three patterns mentioned above and tentative names assigned to the factors. The following statements regarding the nature of these factors are suggestive and not intended to be thought of as final.
- a. A general factor U_1 running through all ten variables probably represents the general fund of sensory motor activity common to all the individuals.
- b. The group factor U_2 running through variables one, three and five seems to be related to motor ability.
- c. The group factor U_3 runs through variables four, nine and ten. This factor is apparently closely connected to the propotent tendencies in the animal, and acts in a negative manner in variable nine, insight B.
- d. The group factor U_4 is found in variables two, three, five and eight, with a negative coefficient in variable eight. The

evidence indicates that this factor is speed which operates beneficially in variables two, three, and five but inhibits the successful solution of variable eight, problem box A.

- e. The fifth factor $U_{\mathfrak{b}}$ running through variables two, three and four appears to be emotional. This emotion seems to have its base in the absence of other individuals, this lack of companions stimulating the chick to considerable activity. The effect of the factors seems to be negative in variable two and three and positive in variable four.
- f. The sixth and last factor is small, running through variables four and six, vocalization and the multiple T maze. The writer has not been able to postulate any reasonable explanation of this particular bond.
- 4. A possible interpretation of the nature of the four factors found in Table XIV and used in reconstructing the correlation of Table XV, is given. These factors are, general nervous activity, spatial relationships, speed in gross muscular activities, and directional tendency.
- 5. There seems to be a tendency in chicks when isolated to emit their cheeps in rhythmic groups. The number varies considerably from chick to chick. This point needs investigation using a mechanical device to determine the regularity and number of cheeps. Chicks vary greatly from individual to individual in their nervous or emotional stability as measured by their cheeps when isolated from others of their kind. The number of cheeps were determined for a thirty second period on four successive days and gave a reliability of .91.
- 6. There are several lines of evidence all indicating that in certain chicks there is a tendency to prefer one direction, that is prefer to turn right or left. The evidence from the different lines investigated is mutually supporting and suggests that the tendency is a reality and not an artifact of the measures used in this investigation.
- 7. The intercorrelations are small, so that a similar investigation into the organization of abilities in chicks may require entirely different patterns to explain the data.
 - 8. The evidence, however, indicates that in animals with the

relatively small amount of insight or ability of young chicks it is necessary to postulate more than a single general factor. As in tables of correlations based on human measurements several patterns can be fitted to the data and more or less plausible interpretations can be attached to these factor patterns.

APPENDIX I

DIRECTIONAL TENDENCY

The evidence from problem box B indicates that the tendency to go right or left in effecting the solution of the problem is the same for the entire group. This evidence is set out in Table XVII.

TABLE XVII

Direction taken by chicks in problem box B

	TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 4	TRIAL 5
R	60	57	63	67	61
L	59	62	56	52	58

TABLE XVIII

Direction taken by chicks in the alternate stimulus box

	TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 4	TRIAL 5	TRIAL 6
R	84	19	102	91	18	18
L	35	100	17	28	101	101

If, however, an animal is definitely stimulated with regard to a particular direction as in the alternate stimulus maze, we get results as shown in Table XVIII. Here the evidence is very strong that when an outside stimulus is applied with regard to a particular direction that the chick will tend to go in the direction stimulated. That this is not perfect may be accounted for in several ways. It may be that the action of going in an opposite direction to that of the stimulus is a matter of chance. The consistency of the proportions in Table XVIII together with their magnitude does not readily lend itself to such a hypothesis, although it does not exclude such an explanation.

Another obvious explanation would be that there is within the chick a tendency to go consistently right or left and that in some individuals this tendency may be so strong as to overcome the tendency to go in the direction of the stimulus when a conflict arises between the tendency and the stimulus.

Some evidence to support this last hypothesis may be adduced from the data gathered on the alternate stimulus box. It is evident from Table IV that the correlation between the scores on the odd and even number trials is consistently,

and with the exception of time, considerably greater than that between halves so chosen that each would contain only one type of directional tendency, i.e., trials 1, 3, and 4, in which the stimulus is always to the right. The correlation of the function, time, is not reduced as much as the other correlations due to the fact that the time limit was sufficiently large that even when a chick went as far as possible in the wrong direction there still remained sufficient time to solve the problem.

Apparently some factor is masked when we correlate the odd-even halves and this factor is of such a nature that when we shift the halves to as to contain only trials with stimulus constant as to direction, the correlation is significantly constricted. This would lead us to expect a negative factor of considerable magnitude, possibly, fundamentally related to direction.

A directional tendency score was assigned to each chick. A value of one was given when the chick went in the direction of the stimulus and a value of 2 was assigned to the direction in which the chick went if that direction was opposite to the stimulus. The following example shows the score determined for a particular chick.

Stimulus	\mathbf{R}	\mathbf{L}	\mathbf{R}	\mathbf{R}	\mathbf{L}	\mathbf{L}
Chick's response	\mathbf{R}	\mathbf{L}	\mathbf{R}	· L	\mathbf{L}	\mathbf{L}
R score	1		1			
L score		1		2	1	1

With a resulting right left score of 2–5. Other weights could be assigned to the responses. This was tried but the resulting scatter diagrams were far from linear, whereas with the scheme outlined above the correlation plot was linear. If all responses were weighted the same, the resulting correlation would, of course, be unity and negative. The correlation within this set of scores is a negative .7529. This is comparable to the value found in problem box B. It should be noted here that this value may be an artifact resulting from the scoring technique and that this coefficient is not substantitive to the argument of a directional tendency. Further and more important evidence may be adduced from problem box B.

Scores were assigned to responses on trials 1, 3, and 5, and to trials 2 and 4 in such a manner that a high score indicated tendency toward the right and a low score a tendency to the left. The correlation between these two scores was .5959. This is of the nature of a reliability coefficient as it measures the consistency of direction on the two sets of trials, so that the consistency of the response over the entire set of five trials can be estimated by the Spearman-Brown formula as .7468. The right-left scores assigned to each chick can be tested to determine if they are artifacts by the following method. The correlation between the R score and the errors on the days when the stimulus is to the left should be greater than the correlation with the errors on the days when the stimulus is to the right. Using the following notation

- 1. Directional tendency to the right
- 2. Directional tendency to the left
- 3. Errors on day when stimulus is to the right
- 4. Errors on day when stimulus is to the left

the correlation between one and four should be greater than the correlation between one and three and further the correlation between two and three should be greater than the correlation between two and four, if the scores are other than artifacts. Calculating these coefficients give

$$r_{14} = .5854 > r_{13} = .3457$$

and

$$r_{23} = .7681 > r_{24} = -.1662$$

and their relative magnitudes are in the expected a priori order, on the assumption that the scores are not artifacts.

In view of all of the evidence with its converging and mutually supporting lines it seems reasonable to expect a directional tendency to exist to a small but appreciable degree in certain individual chicks. This tendency may be due to habit, to nature, or to a combination of both. The fact that it is fairly consistent in some individuals and not in others when all have had the same number of trials may mean only that those individuals form habits more rapidly than the others. Probably there is an innate tendency in certain animals to be, say, left or right eyed (similar to eyedness found in humans), left or right footed, or that there is a definite favoring of the one side rather than the other due to physiological factors such as better vision in one eye. Whatever the cause, innate, acquired, or a combination of these, it seems fairly definite that there is a directional tendency in certain chicks.

APPENDIX II

FITTING FACTOR PATTERNS

The fitting of factor patterns to reproduce the intercorrelations among a set of variables can be done by any one of several techniques. Kelley (1928) proposed a method using a least square technique. Thurstone (1931) has recently developed and published a technique based on higher geometry and the fitting of curves by the method of averages, applicable when it is assumed that the general or group factors are all important in comparison with the specific factors. Another method has been presented by Holzinger and Swineford (1932). Various patterns can be fitted by any one of the three methods depending upon the point of reference chosen. The fact that no one pattern can be arbitrarily fixed on as the "right" pattern is well known. Holzinger and Swineford (1932) using Kelley's seventh grade data demonstrate this point by fitting several patterns all with equally good fits. The patterns vary as to the number of factors, the position of the coefficients and their numerical value. They attribute the variations in part to the differences in the preliminary estimates of additional factors and in part to the method of fitting. The important point about any method is whether or not a reasonable fit to the data can be secured.

The problem of assigning preliminary values and positions to coefficients is solved in part by certain statistical techniques and in part by speculation regarding their nature and location. Certain questions now arise, "What value can these patterns have if they are not determined from a fixed origin and if many patterns can be fitted to the same body of data?" "Which pattern shall be accepted?" The law of parsimony, other things being equal, can be drawn on here and the simplest pattern that fits the data can be chosen as the best pattern. A

better procedure seems to be to fit the simplest possible pattern in terms of number of factors, that is n is a minimum, then fit n+1, n+2, etc., factors until several patterns have been fitted. Better yet, fit several patterns using different assumptions for the preliminary allocation of factors. Then examine these patterns to see which factors consistently run through the patterns. These families of patterns probably give the best idea of the relationship between variables due to a group factor.

The method used in this study was developed by the writer and in general is similar to that presented by Holzinger and Swineford. This is mentioned only as evidence of the validity of the technique. The method is presented somewhat in detail in order to facilitate its application to other data.

The tests employed should be carefully examined as to method of presentation, scoring, apparatus used, skills involved, etc. to determine possible factors due to similarity. If pencil and paper tests are used the form in which the questions are asked may give rise to a group factor. A table bearing this information is of considerable assistance. The table of correlation coefficients should be examined next with the view of locating possible factors, and estimating the preliminary weights to be assigned due to unusually high, low, or negative correlations.

The tetrads should be examined next to determine which combinations, if any, can be explained by one general factor plus specific factors. Whenever such a set is found it should be noted. These sets should be re-examined to check on the consistency of a given pair of variables exhibiting a bond. If the triplet of tetrads resulting from a given pair of variables, say ij, in conjunction with two other variables equal zero, then all other pairs of variables should be considered in connection with the given pair, ij. If three or more such sets of triplets are found to all equal zero, it may be assumed that no group factor lies between this pair of variables, ij, especially if the directed mean tetrad t_{ijxy} is small. By the directed mean tetrad is meant the mean value of all tetrads where the variables, ij, are fixed and x and y are allowed to vary.

The next step is to determine the directed mean tetrad values for all combinations of the variables taken two at a time. This may be done in either of two ways, first by adding up all the tetrads t_{ijkl} where ij remain fixed, then assigning another value to ij and summing again, or by using the formula described on page 31

From the directed mean tetrads, first select those which are zero or within one sigma of zero. The formula for determining this standard deviation is given on page 31. The indication is, if the directed mean tetrad is less than one standard deviation, that between these pairs only a general factor is to be expected. Second, select those tetrads which exceed two standard deviations and assign a special bond to that group. This outlines roughly the method used in making the first estimate as to the position of the factors. The next step has to do with the assigning of values to the pattern determined on.

It must be kept in mind that the above pattern is temporary and subject to revision after values have been assigned the general factor. A subjective but reasonable check on the validity of the position of the factors is found in the number of changes necessary.

Now let us examine a pattern in which the factors and the position of the coefficient has been determined. Table XIX gives the original correlation coefficients and Table XX the preliminary estimate of the position of the coefficients This data is artificial and as a result can be fitted more easily than real data, but will suffice for the purposes of illustration.

Examination of each pair of variables in Table XX reveals that no group factor is necessary to account for the correlations, 14, 15, 17, 24, 25, 26, 27, 34, 35, 36, 37, 46, 56, 67.

TABLE XIX
Original table of correlation coefficients

	1	2	3	4	5	6	7
1							
2	.32						
3	.39	.50					
4	.16	.20	.24				
5	.12	.15	.18	.30			
6	.48	.30	.36	.24	.18		
7	.20	.25	.30	.38	. 51	.30	-
	1				1		

TABLE XX
Postulated location of factors to explain intercorrelations

	α	β	γ	δ	S_i	S_c
1	*	*		*		
2	*	*				
3	*	*				
4	*		*			
5	*		*			
6	*			*		
7	*		*			
		1)		

Spearman (1927) has shown that if one general and three specific factors are sufficient to explain the correlations between three variables, 1, 2, and 3, then the weight assigned to α_1 is determined from

$$\alpha_1 = (r_{12}r_{13}/r_{23})^{\frac{1}{2}} \tag{1}$$

Kelley (1928) gives a similar proof. The next step is to solve the various triads resulting from combinations of the above coefficients where

$$t_{123} = r_{12} r_{13}/r_{23}$$

Determine the weight to be assigned the α factor for each variable by taking the median value of the various determined weights for each variable. It is possible to determine from the coefficients the weights for variables 2, 3, 4, 5, 6, and 7. The following triads can be formed, t_{246} , t_{256} , t_{267} ; t_{346} , t_{356} , t_{367} ; t_{426} , t_{436} ; t_{526} , t_{536} ; t_{624} , t_{625} , t_{627} , t_{637} , t_{637} , t_{634} ; t_{726} , t_{736} . The first subscript is the one common to both correlations in the numerator. The root of these triads gives the corresponding α factor. In the case of variable 2 there are three values for α_2 , and the median

value is chosen. In this artificial problem all the values come out .5, but this rarely occurs in real data so in practice the median value should be chosen. It is possible to solve for α_2 , α_3 , α_4 , α_5 , α_6 and α_7 directly from the above sets of triads.

Note that α_1 cannot be determined here by the reduction of a triad, so that other methods must be employed. An examination of Table XX shows no extra bond between variables 1 and 4, 1 and 5, 1 and 7. Divide r_{14} by α_4 , and get a value for α_1 , similarly r_{15} by α_5 and r_{17} by α_7 . Take the median of these three values as the value for α_1 . Substitute the α values in Table XX. The result is shown in Table XXI. It is necessary now to estimate the correlations in terms of factor weights available, for example $r_{12} = \alpha_1 \alpha_2$, $r_{34} = \alpha_3 \alpha_4$, $r_{67} = \alpha_6 \alpha_7$, etc. The original correlations, the estimated correlations and the differences are shown in Table XXII.

TABLE XXI Factor pattern for the intercorrelations in Table XIX, after the α weights are estimated

	α	β	γ	δ	S_i	S_c
1	4	*		*		
2	5	*				
3	•6	*				
4	.4		*			
5	.3		*			
6	. 6			*		
7	. 5		*			

An examination of Table XXI shows that the β factor appears in variables 1, 2, and 3, and that there is no common group factors. This is permissible for the α column is suppressed in this examination as all the α values have been determined. Using the values of the differences in Table XXII as the values for the correlations and noting the r_{12} , r_{13} , and r_{23} now show no group factor, solve the triads t_{123} , t_{213} , and t_{312} for the β values. For example β_1 equals $(t_{123})^{\frac{1}{2}}$, which equals the square root of $(.12 \times .15)/.20$ or .3. Enter these values in the appropriate cells in Table XXI.

A further examination reveals that the γ factor appears in variables 4, 5, and 7 and that there is no common group factor. Again, using the differences in Table XXII as the values for the corresponding correlations solve the triads t_{457} , t_{547} , and t_{745} . Enter the γ values in Table XXI, and there results a pattern such as shown in Table XXIII. The values of δ_1 and δ_6 present a very different type of problem, and only an estimate can be made as to their precise values. It is necessary to again estimate the correlations using this time the α , β , and γ factors. The estimated correlation r_{12} equals $\alpha_1\alpha_2 + \beta_1\beta_2$, in like manner, r_{47} equals $\alpha_4\alpha_7 + \gamma_4\gamma_7$, and the other coefficients determined similarly. The observed correlations, the estimated coefficients and the differences are shown in Table XXIV.

The difference between the observed and estimated correlation r_{16} is .24.

TABLE XXII

The observed correlations, the estimated coefficients in terms of α 's from Table XXI, and the differences

<i>r</i>	OBS.	EST.	DIF.	r	OBS.	EST.	DIF.	r	OBS.	EST.	DIF.
12	.32	.20	.12	24	.20	.20	.00	37	.30	.30	.00
13	.39	.24	.15	25	.15	.15	.00	45	.30	.12	.18
14	.16	.16	.00	26	.30	.30	.00	46	.24	.24	.00
15	.12	.12	.00	27	.25	.25	.00	47	.38	.20	.18
16	.48	.24	.24	34	.24	.24	.00	56	. 18	.18	.00
17	.20	.20	.00	35	.18	.18	.00	57	.51	.15	.36
23	.50	. 30	.20	36	.36	.36	.00	67	.30	.30	.00
	1	1		11	1	1	1		l	1	1

TABLE XXIII $\textbf{Factor pattern for the intercorrelations in Table XIX, after the α and β weights } \\ \text{are estimated}$

	α	β	γ	δ	s_i	S_c
1.	.4	.3		*		
2	.5	.4				
3	.6	.5				
4	.4		.3			
5	.3		.6			
6	.6			*		
7	. 5		.4			

TABLE XXIV

The observed correlations, the estimated coefficients in terms of α 's β 's, and γ 's from Table XXIII and the differences

r	OBS.	EST.	DIF.	r	опѕ.	EST.	DIF.	r	OBS.	EST.	DIF.
12	.32	.32	.00	24	.20	.20	.00	37	.30	.30	.00
13	.39	.39	.00	25	.15	.15	.00	45	.30	.30	.00
14	.16	.16	.00	26	.30	.30	.00	46	.24	.24	.00
15	.12	.12	.00	27	.25	.25	.00	47	.38	.38	.00
16	.48	.24	.24	34	.24	.24	.00	56	.18	.18	.00
17	.20	.20	.00	35	.18	.18	.00	57	.51	.51	.00
23	. 50	.50	.00	36	.36	.36	.00	67	.30	.30	.00

There is no indication how this should be divided or distributed between δ_1 and δ_6 . It may be .8, .3; or .3, .8; or .4, .6; or .6, .4; or $\sqrt{.24}$; or any other combination except that no factor may have a value greater than unity (in this case the maximum value for δ_1 is .875 and for δ_6 is .693). (See condition 1 in the summary.) In such a case one cannot precisely determine the coefficients. However, if the

reliability coefficients are given, the limits for these two values can be determined. Thus the residual difference, .24, is divided in such a manner as seems reasonable and falls within the conditions outlined below.

The coefficients in Table XIX are artificial. In practice several difficulties enter into the application of this technique. First, it is difficult to hit upon the true pattern of the coefficients. Second, the errors of measurement enter (the unreliability of the data) into the coefficients. Third, in the calculation of the coefficients, such factors as width of interval, rounding of decimals, number of places kept, shift the observed values of the coefficients. Fourth, in general the fits are not so precise as a result of using median values (which are not necessarily correct) for the factors. If a closer fit is desired it must be secured by the trial and error method. It may be necessary in this trial and error method either to adjust values already determined or to postulate additional factors. It is possible sometimes to combine the factors in two or more columns thus reducing the number of factors first estimated. The differences between the observed and estimated correlations may shift from plus to minus while fitting but little attention need be paid to this, although consideration of this is necessary at certain times in choosing the appropriate triad.

The two specific factors for each test are determined last. One of these factors, Sc, results from the unreliability of the test and is found from the formula

$$Sc_1 = (1 - r_{11})^{\frac{1}{3}} (2)$$

The second specific factor is determined from the formula

$$Si_1 = (r_{11} - \alpha_1^2 - \beta_1^2 \dots - \eta_1^2)^{\frac{1}{2}}$$
 (3)

The specific chance factors are determined next by substituting the reliability coefficients in formula (2). The second specific factor Si can be determined from formula (3).

A summary of certain important conditions that must be met in the fitting of factor patterns follows.

- 1. The sum of the squares of the α , β , η values and the two specific values for a given variable must sum to unity.
- 2. Where reliability coefficients are available specific factors with coefficients of $(1-r_{11})^{\frac{1}{2}}$ can be determined.
- 3. The sums of the products under common factors for two variables give approximately the original correlations.
- 4. For n variables there are n(n-1)/2 correlations and n reliability coeffi-There are also n expressions of the type $\sum_{i=1}^{n} k_{ij}^2 = 1$, where i is a given row and j the columns, so that k_{ij}^2 is the square of the value in the cell formed by the intersection of the i^{th} row and j^{th} column. Thus the total number of conditions is n(n + 3)/2 when the reliability coefficients are available and n(n+1)/2 without the reliability coefficients. The evaluation of these functions determine the maximum number of factor coefficients that can be used in a determinate solution.
- 5. Holzinger and Swineford give the following conditions to be met in determining the goodness of fit of a given pattern.

$$\sum_{i=1}^{N} k_{ij}^{2} = 1 \tag{4}$$

$$\sum_{j} k_{ij}^{2} = 1$$

$$2\Sigma r + n = (\sum_{1}^{j} k_{i1})^{2} + (\sum_{1}^{j} k_{i2})^{2} \dots + (\sum_{1}^{j} k_{ij})^{2}$$
(5)

Two other functions should also be investigated, namely

 M_d = mean difference between the original correlation coefficients and those estimated from pattern (6) δ_d = standard deviation of the differences between the original

correlations and those produced by the pattern (7)

6. Further, the maximum difference between the paired correlations should not exceed the standard error of the median correlation coefficient.

This technique for fitting factor patterns can easily be followed with a fair degree of speed. It should be kept in mind that no pattern is unique for a given table of correlation coefficients. Possibly trends exhibited by a series of patterns will give a more valid estimate of the location of group factors than can be deduced from a single pattern.

APPENDIX III

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THE MODIFICATION OF VESTIBULAR NYSTAGMUS BY MEANS OF REPEATED ELICITATION

BY

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THE MODIFICATION OF VESTIBULAR NYSTAGMUS BY MEANS OF REPEATED ELICITATION

O. H. MOWRER

From the Psychology Laboratory of the Johns Hopkins University

I. THE PROBLEM

The characterization of reflexes as "highly stable," "mechanically determined," "inevitable," "fixed," "predictably certain," "machine-like," and "invariable" has long been an established tradition in the biological sciences. The comparatively recent discovery that many of the so-called reflexes may be profoundly and more or less permanently modified through "practice" has therefore proved extremely disconcerting, especially to those individuals who have relied upon the "invariability" doctrine as a fundamental diagnostic implement or who have embraced it because of its pedagogical simplicity and convenience. Although experimentation has revealed that numerous other reflexes notably, the knee-jerk, the blink, the pupillary and the post-contraction proprioceptive reactions—may be substantially altered by means of repeated elicitation under appropriately chosen experimental conditions, the most conspicuous example of susceptibility to this type of modification is afforded by the response commonly designated as vestibular nystagmus. Because of the particularly important diagnostic significance assigned by many otologists and neurologists to this latter response, its "functional" modifiability has been acknowledged with great reluctance; but the evidence accumulated through both controlled research and casual observation so consistently attests the validity of this phenomenon that it can no longer be either ignored or denied. A wide variety of investigations with both human and animal subjects have decisively demonstrated that this response may be strikingly reduced in both duration and magnitude by means of repeated elicitation; and any further experimental endeavor merely to add to the already abundant evidence in this respect would be largely gratuitous. However, despite the general recognition now accorded to the reality of this phenomenon, there still exist considerable obscurity and difference of opinion regarding its probable explanation and the conditions essential for its occurrence. In view of these circumstances it is the purpose of the present study to review the various hypotheses which have previously been advanced in this connection and to attempt to determine experimentally and analytically which of them constitutes the most plausible explanation of the phenomenon in question.

II. HISTORICAL BACKGROUND

The first and, indeed, in many respects the most noteworthy attempt to give a comprehensive account of the reduction of vestibular nystagmus by means of repetition was made in 1906 by Abels (1). For many years a ship's physician, this writer became much interested in the phenomenon of seasickness, one of the most striking characteristics of which he found to be its remarkable susceptibility to "habituation" (Gewöhnung). Thus, as "anyone who has been employed at sea for some time" can readily testify, the typical symptoms of this malady usually "diminish significantly within hours or days; and on similar occasions in the future, if the interval is not too long, they do not re-appear with the same intensity. In any case, habituation is attained much more quickly in a second similar experience."

Likewise:

The facts of habituation in the case of dizziness are generally known. Learning to dance offers one of the most pertinent examples. Many people are overcome during the first attempts by violent dizziness and after-dizziness, which often last for minutes. But within a few days, and very often after a few hours in one day, these phenomena disappear entirely or virtually so. It is striking that when dancers who have already engaged in ordinary dancing [to the right] for a long time first try dancing toward the left, they generally undergo phenomena similar to, although perhaps weaker than, those incident to their first attempts at dancing. If dancing is not practiced for some time, more sensitive

individuals undergo a repetition of the same phenomena as in the beginning; only now habituation usually progresses much more rapidly than originally.

In a report published just prior to that of Abels, Ruppert (64) observed that persons much given to the popular social dances of the time were likely to show a sub-normal nystagmus when tested in a revolving chair and that this deviation from the average was usually greater for the direction of rotation most frequently involved in dancing; which latter observation, it will be noted, is strictly parallel to the observation of Abels regarding the greater immunity of dancers to the dizziness produced by rotation in the practiced than in the unpracticed direction. Feeling that it "was desirable to establish the above relationships objectively in animals," Abels performed the following experiment. Using pigeons as subjects, he placed them in a special cage which was suspended by two cords and in which the birds were free to move about. The cage and the birds could therefore be "twisted up" so that when released, they would revolve with increasing velocity until either the cords were untwisted or the cage was forcibly brought to rest by some other means.

The average rotation speed was rather considerable. The chief point stressed was to stop the apparatus suddenly after two or three dozen rotations, in order to adapt the animals especially to this act. Rotations were repeated several times a day so that every animal had to undergo in the course of the day several hundred rotations, and this was continued for several days. During this [practice period] every animal was rotated only to the right or to the left. It was thus possible to observe that the phenomena which were very violent in the beginning, when the apparatus was stopped, gradually became milder and finally were limited to a few nystagmic jerks. If now, at this stage, an animal were rotated in the unaccustomed direction, it showed, when brought to rest, the same violent phenomena as in the beginning—falling of the entire body and extremely vigorous and prolonged nystagmus. We have here the analogy of the results observed in men.

Under the conditions just described, vision was not excluded; the walls of the cage were merely of such material as "to give the eyes of the animal the fewest possible points of fixation." Consequently,

Experiments were also undertaken in which visual perceptions were excluded. The apparatus was covered with a cloth, and an opening was left only at the top for the observation of the behavior of the pigeon. In such experiments it is known that no nystagmus is observed during rotation.\(^1\)... With the stopping of rotation, however, very strong nystagmic jerks may always be observed; and it is now striking that the intensity of the jerks decreases much less during the course of days than in the animals rotated in the open apparatus, that is, the habituation, although undoubtedly present as is proved by later rotation in the unaccustomed direction, is still much less pronounced than in the first experiment.

Abels fully appreciated that any adequate explanation for the reduction of vestibular nystagmus by means of repeated elicitation must necessarily be predicated by a clear conception of the physiology of the vestibular mechanism as such; and it was largely because none of the traditional theories of vestibular functioning could be made to provide a plausible basis for such an explanation that the problem had previously "been given scarcely any attention."

A conspicuous peculiarity of the vestibular reaction system—and one which any satisfactory theory of the physiology of the vestibular mechanism must take into full account—is that a momentary or very brief angular acceleration, or retardation, elicits responses (and sensations) which usually last many times as long as the actual objective stimulus, providing that an opposing stimulus does not occur and therefore interrupt these aftereffects. In the original "hydrodynamic" theory of Mach (49), Breuer (10), and Brown (12), an attempt was made to account for this striking discrepancy between the duration of vestibular stimulation and response by assuming that the angular acceleration, or retardation, produces movement of the fluids contained within the semicircular canals, which, by virtue of the inertia of

¹ The fact that this particular statement is not entirely accurate in no way invalidates the remainder or Abels' remarks.

these fluids, persists and therefore continues to elicit vestibular reactions for a considerable time after the actual, external stimulus has been withdrawn. Mach (50) shortly abandoned this explanation, however, having convinced himself through observations made with a glass model of the labyrinth that it is a physical impossibility for any fluid to "flow" within a closed system of the shape and dimensions of canals for more than a very few seconds after the cessation of either acceleration or retardation. continued to regard movement of endolymph as the immediate cause of the vestibular responses produced by bodily rotation: but the prolonged persistence of these reactions he attributed to the action of a central mechanism, probably located within a subcortical center,2 which tends to perpetuate neural conditions equivalent to those produced during actual, peripheral stimulation until either (a) there occurs an opposite type of peripheral stimulation or (b) this central mechanism is "exhausted," so to speak.

Breuer (11) acknowledged the cogency of Mach's objections to the original form of the hydrodynamic theory but refused to accept Mach's conception of a central neural mechanism as the explanation for the persistence of vestibular responses after the cessation of external stimulation. Instead, Breuer merely revised the hydrodynamic theory in such a way as to make this phenomenon dependent upon a hypothetical distortion or bending of the cupulae and attached sensory epithelia, which he assumed to be produced, to a greater or lesser degree, by any movement of endolymph, however brief, and which Breuer further assumed to persist (a) until corrected by a reverse movement of endolymph or (b) until the natural (presumably rather low-grade) elasticity of the displaced structures eventually brought them back to their normal position. Breuer (11) made a cautious attempt to apply this theory of vestibular functioning to what he himself recognized as "the great capacity for adaptation which the organ of movement-sensation certainly has."

I think it necessary now to regard it as conceivable in all these cases [of adaptation] that the elasticity of the hairs increases gradually under the influence of endolymph impacts occurring more frequently in the

² Cf. the recent histological studies of Lorente de Nó (45), (46).

generally unaccustomed direction; and, not compensated for by opposite impacts, they regain their normal position more quickly and the corresponding duration of the after-sensation of movement, i.e., dizziness, decreases.

Abels (1) criticised the plausibility of this explanation in the following words:

I must admit that it is very hard for me, and so far as I can see, also for others, to conceive how the so-called hair-cells (Hörhaare), i.e., the epithelial structures, could undergo such a change in their essential functional peculiarities in such a brief time, in the course of days or even hours. A change of this sort we are ordinarily accustomed to think of as occurring only in certain parts of the central nervous system.

On the basis of experimental evidence which cannot be pertinently described here, Abels not only refused to accept the original hydrodynamic theory as an explanation for the persistence of nvstagmus and other vestibular phenomena after the cessation of external, physical stimulation but also repudiated the revised theories of both Mach and Breuer. For reasons which again cannot be given here without a long digression, Abels concluded that the prolonged after-effects of vestibular stimulation can be most satisfactorily accounted for by positing an intimate integration of both peripheral and central factors into what he termed a "sensation complex." Under the usual conditions of life—in which bodily rotations are ordinarily of brief duration and limited angular magnitude—, the central and peripheral factors comprising this "sensation complex" combine harmoniously and mutually complement each other. On the other hand, in the case of prolonged bodily rotation—where the effects of acceleration are so remote temporally from the effects of retardation that the normal occurrence of mutual interaction is prevented disharmony develops between the various elements of the "complex" and, with sufficient repetition of this situation, the elements gradually become dissociated and the "complex" disintegrates. The reduction in nystagmus and the disappearance of dizziness are manifestations of this disintegration process.

As a possible alternative hypothesis, Abels suggested that the

reduction of nystagmus and related vestibular phenomena by means of repetition, instead of being due to a strictly pathological process, namely, the gradual breakdown of normal integration. may represent, on the other hand, a positive and useful kind of adjustment to new and unusual circumstances. This type of adjustment Abels compared to the "learning" involved in adaptation to monotonous "uniform noises, like the rippling of the brook or the ticking of a clock, which, although the impressions are always received in the same manner by the end organ, do not come into consciousness during concentrated mental activity." Although Abels appeared to regard the "dissociation" theory as by far the more satisfactory explanation of nystagmus habituation, subsequent writers in this field have been inclined, as later pages will show, to favor the "learning" hypothesis. However, the appearance of an article about to be reviewed cast so much doubt upon the actual reality of this habituation phenomenon that the problem of determining its probable explanation was scarcely so much as mentioned for more than a decade.

In a paper published in 1907, Robert Bárány (7), a Viennese otologist and later Nobel prize winner, turned his attention to the matter of nystagmus habituation. Just prior to this, Bárány (4), (5), (6) had been actively engaged in an attempt to show that the duration of post-rotational nystagmus constitutes a reliable clinical index to the functional integrity of the non-acoustic labyrinth, or vestibular apparatus; and he was therefore not slow to appreciate the bearing of Abel's experimental findings and theoretical contentions upon his own claim that vestibular nystagmus is a relatively fixed and invariable reflex in all "normal" subjects. Bárány readily admitted that Abels had unmistakably demonstrated habituation of head nystagmus in pigeons; but, says he,

We must not forget, however, that head nystagmus does not exist in men and that the results of this [Abels'] investigation are therefore not transferable to men. Consequently it was important to study the effect of habituation in men. I myself have made such a study with a single subject and for 14 days have rotated him every day 50 or 60 times in the

revolving chair. No effect upon the duration of the after-nystagmus was to be observed (7).

Bárány (7) found that professional dancers who whirl only to the right show an after-nystagmus of only about 30 seconds when passively rotated in that direction, which is considerably less than the 41-second average which he found for the same direction of rotation in a group of "normal" subjects. On the other hand, Bárány found that these same dancers showed an after-nystagmus of 49 seconds when passively rotated to the left, i.e., in the unpracticed direction, which is appreciably above the 39-second average of the naïve subjects for the same direction of rotation. In dancers who make a practice of whirling in both directions, Bárány found no significant variation in the after-nystagmus for either direction of passive rotation from the averages obtained from the control group.

Although practiced dancers repeatedly informed Bárány of their immunity to dizziness, he believed that this type of habituation was not accompanied—at least not in those dancers who whirl in both directions—by a corresponding reduction in nystagmus. As early as 1820, Purkinje (63) pointed out that there is always a strict correspondence between the direction, duration, and intensity of vestibular nystagmus and the direction, duration, and intensity of the visual vertigo (i.e., the illusory rotation of the environment produced by the eve movements comprising the nystagmus); and it is therefore difficult to conceive how either the nystagmus or the visual vertigo (which is presumably what Bárány meant by "dizziness" (Schwindel)) could vary to any significant extent independently of the other. Bárány summarily dismissed this difficulty, however, with the remark that "only the subjective accompaniments of nystagmus become unnoticeable, while the nystagmus itself shows no significant weakening" (7). The unreasonableness of this assumption³ (widely accepted by

³ Since the above was written, the writer has had occasion to examine a limited number of professional exhibition skaters and, also, certain members of the Monte Carlo Ballet Russe (through the courtesy of M. the Director General W. de Basil and M. the Regisseur S. Grigorieff). These individuals were asked to "spin", in characteristic manner, and permit the writer to observe their

many otologists (48), (41), (42), (51), (25)) as well as the unreliability of Bárány's experimental observations will be made manifest in subsequent pages.

So eminent was Bárány professionally and so completely did his dicta dominate otological theory and practice that only twice (to the writer's knowledge) during the decade succeeding the publication of the paper cited above (i.e., from 1907 to 1917) was the subject of nystagmus habituation referred to in the literature and then in a manner not wholly incongruent with Bárány's point of view. Thus, in 1909, Wintermute (65) wrote as follows:

In testing a person who, by occupation, is constantly revolving in one direction, the normal reactions will not hold. Ballet dancers who whirl only in one direction, which is the rule, show great difference in the resulting nystagmus when turned to the right and left. When

eyes immediately afterwards. In many cases, there was no detectable postrotational nystagmus whatever. In certain other cases, a noticeable (though distinctly "sub-normal") nystagmus was present, in which event a concomitant visual vertigo was also present, except in one subject, Miss Nellie Prantell of the New York Skating Club. Miss Prantell showed a nystagmus subsequent to whirling of 5 to 8 seconds' duration but insisted that she experienced no illusory movement of the visual environment under these circumstances. This remarkable testimony suggests that the assumption of Bárány cited above may, in exceptional instances, be valid; that is to say, it is not wholly improbable that an occasional individual may learn to interpret the visual consequences of postrotational nystagmus in such a manner as to eliminate the apparent movement of the environment. This, however, is a matter which will need to be subjected to a careful experimental analysis before a final conclusion may be reached.

In this connection it is perhaps pertinent to call attention to a statement by Holsopple (37) to the effect that in some individuals the nystagmus produced by passive bodily rotation may be greatly reduced in duration by means of repetition without the duration of the post-rotational illusion of bodily turning (which characteristically appears if the eyes are kept closed) seeming to be in anyway affected. Here would appear to be a situation somewhat analogous to that hypothecated by Bárány. However, since it has been repeatedly demonstrated that post-rotational nystagmus ordinarily lasts much longer when vision is excluded than when vision is permitted (58) and since Holsopple tested the duration of the post-rotational nystagmus of his subjects with their eyes open and the duration of the post-rotational illusion of bodily turning with the eyes of his subjects closed, there is some reason to suppose that in the latter situation the nystagmus may have regularly lasted quite as long as the illusion of turning. Here, again, further experimental inquiry is obviously needed.

turned in the direction in which they are used to revolving the nystagmus is very small, as a consequence of their continual practice.⁴

Then in 1914 Güttich (34) reported that repeated administration of the Bárány rotation test usually results in a marked decrease in the duration of the nystagmus thereby elicited. However, this writer was inclined to attribute this diminution of nystagmus to a decline in the general nervous tension and hyperirritability which subjects usually manifest during the first few administrations of the test, rather than to any real reduction in the strength of the reflex. Although Güttich's observations are thus opposed to the experimental results reported by Bárány, this writer does not, however, voice any objection to Bárány's assumption that vestibular nystagmus is fundamentally fixed and invariable.

III. THE MINEOLA CONTROVERSY

For several months prior to the United States' entrance into the World War in 1917, it appears that a group of American otologists "had been in correspondence with the Medical Department of the United States Army upon the subject of the physical requirements of applicants for the flying forces" (51) and had convinced the medical officials that "by demonstrating an actively normal organ of equilibrium in every prospective aviator, this Government will avoid many costly accidents in the air which otherwise would be avoidable" (3). The result was that when war was actually declared, this same group of otologists was put in charge of special clinics in "each of 35 cities throughout the United States for the examination of candidates for the aviation service" (42), and in these clinics the Bárány rotation test made the almost exclusive basis for the determination of specific flying ability. In fact, this test was regarded by the otologists and certain army officials as having such high diagnostic value in this connection that during the first few weeks of

⁴ Although Wintermute speaks as if these observations might have been original, it seems not unlikely that he merely borrowed them from Bárány, whom he cites as authority for numerous other statements.

America's participation in the war, "there was no medical examination—beyond a rotation test—before a man began flying" (2).

The great importance thus attached to the rotation test seems to have involved two major fallacies. In the first place, there was apparently a gross over-emphasis upon the rôle of the vestibular mechanism in flying. This, however, has been considered in another connection (55) and need not be further discussed at this time.

The other fallacy—and the one of greater significance for the present discussion—was the illicit inference that since all individuals with demonstrably pathological non-acoustic labyrinths show unusual reactions to bodily rotation, then all individuals who show unusual reactions to bodily rotation must, ergo, have pathological labyrinths. Thus to quote:

We start out with a fixed and definite idea that a normal internal ear, intact nerve pathways leading to normal centers, will *invariably* produce a rhythmic nystagmus and vertigo when a stimulus is applied.... If, on the other hand, stimulation of the internal ear fails to produce one or all of these responses, the evidence points positively to an impairment at some point of this apparatus (24).

However, some months after the otologists, wholly oblivious of the clinical as well as experimental observations reviewed in the preceding section of this paper, had been put in charge of the selection of candidates for the air service and several hundred men had been barred from entering and some men already having brilliant flying records actually ejected from the service on the basis of the above-mentioned test, serious misgivings began to arise in certain quarters as to whether this test could invariably be relied upon to test what it was supposed to test, namely, the normality or abnormality of the non-acoustic labyrinth.

Suspecting that the veteran aviators who had been tested by the otologists and barred from further service because of subnormal nystagmus had acquired this peculiarity of response as a result of the repeated bodily rotation to which they had been subjected in connection with "stunt" and "combat" flying, Major Knight Dunlap, then head of the Department of Psychol-

ogy of the Medical Research Laboratory at Mineola, Long Island, detailed Captain George Wells, in May, 1918, to obtain the post-rotational nystagmus time of a group of professional acrobats and whirling dancers in New York City. That the results, whatever they might be, could not be discredited by a charge of incompetency on the part of the examiner was assured in advance by having the tests actually administered by an army otologist who had expressed his willingness to co-operate in this enterprise. The data thus obtained, which were carefully scrutinized by Major Dunlap and others, showed that these New York subjects (in whom a perfect sense of balance was obviously imperative for professional proficiency) had, in almost every case, a nystagmus time far below the minimum (16 seconds) set by the otologists for admission into, or continuation in, the air service. In fact, so strikingly did these findings confirm the supposition that repeated bodily rotation may reduce nystagmus that they were taken in charge by a medical officer and suppressed. Certain data, published later and purporting to be the nystagmus measurements of a group of acrobats and dancers whose initials were those of the group measured under Captain Wells' supervision, are not, however, the data for these individuals.5

Parsons and Segar (60), Fridenberg (27), and a few other writers were inclined at this time to agree with Major Dunlap and his colleagues that "trapeze performers and Russian dancers have very little, if any, nystagmus after whirling" and that "men who have a so-called 'normal' nystagmus time before flying often lose all or a great part of it after numerous flights" (60). However, the majority of the army otologists persisted in their contention that nystagmus habituation does not occur as a result of repeated bodily turning. Thus, Jones (42) emphatically declared that "All experienced aviators that have been examined have, without exception, shown normal responses in the turning-chair." Likewise, Fisher and Babcock (26) wished to "have it definitely settled once and for all that army aviators do not lose

⁵ Statements occurring in this section which are not otherwise documented are based upon information obtained by the writer directly from Professor Dunlap.

their nystagmus as a result of the rotation and whirling to which they are subjected."

In the hope of bringing this controversy to an end, Major Dunlap, commissioned Captain Madison Bentley to begin an experiment at the Mineola laboratory, on June 6, 1918, with six enlisted men as subjects (51). Each man was subjected to a schedule of daily rotation which consisted of five periods of clockwise rotation, each period comprised of ten turns at the rate of approximately one revolution in two seconds, followed by five similar periods of rotation in the opposite direction. The successive periods of rotation were separated by rest intervals of about two minutes; the rotation was done by hand, with the subject sitting upright in a specially constructed revolving chair. In all, one hundred revolutions, fifty in one direction and fifty in the other, were given to each subject daily. The following table shows the reduction in the nystagmus time of each of the six subjects during the first ten days of the experiment.⁶

BUBJECTS	ORIGINAL TIME	FINAL TIME	REDUCTION
	seconds	seconds	seconds
Α .	30	12	18
В	27	10	17
C	26	11	15
R	21	14	7
S	25	8	17
w	28	15	13

The results of this experiment aroused a storm of protests and objections on the part of the otologists; abnormality of subjects and incompetence on the part of the experimenters were advanced as possible explanations of these findings, and even insinuations regarding the scientific integrity of those in charge of the project were made. In September of the same year (1918), the otologists, hoping to obtain different results, initiated an experiment similar to the one conducted by the psychologists. They used ten adult subjects and about the same schedule and method of rotation.

⁶ The experiment was continued for an additional ten days with a still further, though relatively less conspicuous, decline in the nystagmus of the six subjects.

This experiment was reported to have been continued for nine weeks, at the end of which time it was admitted that there had been a reduction in the duration of the post-rotational nystagmus "in some cases": but it was insisted that this reduction merely represented an "increased control of the voluntary eye movements" and was "in no sense the result of changing character or intensity of the vestibular stimulus" (2). This latter remark is, of course, quite beside the point; so far as the writer is aware, no one had previously suggested that the repeated rotation involved in the habituation of nystagmus alters either the "character or the intensity of the vestibular stimulus." The real point at issue was whether repeated bodily rotation does or does not tend to reduce the duration of the nystagmic responses; and the otologists themselves, despite their best efforts to the contrary, had confirmed the contention that such a reduction does occur under these conditions.

That "increased control of the voluntary eye movements," i.e., greater facility in "voluntary fixation of the gaze," may have been to some extent responsible for the decrease in the duration of post-rotational nystagmus observed both by the psychologists and the otologists is not entirely improbable; but, for reasons clearly stated by Griffith (32), this could not have been the only explanation for the observed effect. Moreover, it has subsequently been demonstrated that nystagmus habituation may occur when the subject is practiced with vision entirely excluded, that is to say, under conditions in which fixation is impossible and the "control of the voluntary eye movements" otherwise extremely difficult.

Major Dunlap, on the other hand, refrained at this time from advancing any particular explanation for the reduction of nystagmus produced by repeated bodily rotation. He summarized his position in the following words.

Repetition of turning certainly leads, under certain circumstances, to a decrease in after-nystagmus. But that the decline depends in any fixed way upon the length of the temporal interval can not be maintained upon the basis of the evidence at hand [Cf. Holsopple (38)]. The decline is not to be laid to a simple process of adaptation in the receptor

organs of the labyrinth, for such sensory adaptations as are best known—visual, tactual, and thermal—are of brief duration, and furthermore, they rapidly disappear with the lapse of stimulation. Still less is the effect of repetition to be disposed of as a case of 'fatigue,' a term which the uncritical lay reader might readily suggest. Nothing like fatigue (used in the sense of waste products and lowered metabolism) is here observed; and the proposal of that term as an hypothesis would be a loose use of the argument from analogy, which explains nothing. If genuine fatigue were actually induced by rotation, its effects would scarcely remain unmodified for four or five days. The explanation of the observed decline in nystagmus remains, therefore, for further experimentation made under more favorable technical conditions than the department [of psychology at Mineola] has been able to command (51).

IV. SUBSEQUENT EXPERIMENTATION

The controversy between the army otologists and psychologists at the Mineola Laboratory, which has been discussed in the preceding section, naturally had numerous post bellum echoes and stimulated a variety of experimental studies. These studies, which have been reviewed by Griffith (32), (33), Holsopple (36), (37), and others, will, however, be mentioned here only in the most cursory manner.

Griffith (29) subjected sixteen college students to a program of repeated daily rotation, thereby reducing the average nystagmus time of the group 79 per cent. This writer gives the following summary of his results.

We have found that, as turning is repeated from day to day, the duration of the after-nystagmus, the number of ocular movements made, and the duration of the apparent movement [visual vertigo] rapidly decrease. The major part of this decrease occurs within the first few days. The decrease takes place not only from day to day but also within a period of ten trials on any single day. The amplitude of the ocular movements and the number of movements made per second also decrease as repetitions increase.

Griffith, who also reported strictly analogous results from the repeated rotation of white rats (30), made no attempt to offer an explanation for the reduction of vestibular nystagmus by means

of repeated elicitation other than to suggest that "a 'nystagmus curve' is quite comparable with the common 'learning curve,' save for the absence of plateaus."

Dodge (14) suggested that it was "conceivable that the decrease of nystagmus which he [Griffith] observed was really an increased control of eye-movements by visual fixation" (which, it will be recalled, is the hypothesis that had been advanced by the army otologists (2)). Dodge subjected himself to an intensive schedule of repeated bodily rotation under conditions in which the possibility of visual fixation could be controlled and the nystagmic responses graphically recorded. The results obtained by Dodge in his experiment "furnish striking and complete confirmation of Griffith's results together with important additional data." Of these latter perhaps the most significant is the finding that repeated rotation in only one direction decreases the afternystagmus produced by rotation in this direction about twice as much as it decreases the afternystagmus for the unaccustomed direction.⁸

On the basis of his experimental data, Dodge concluded that nystagmus habituation is probably a form of "learning," comparable to or perhaps identical with the learning displayed by human beings and other animals in the gradual abandonment of responses found to be useless or actually harmful under the circumstances in which most frequently elicited. A rat learns

⁷ In a later publication (32), Griffith remarks that: "Numerous observers have reported the course of the recovery that takes place in animals after surgical means of exciting the canals have been resorted to. In most cases the recovery (indicated by the disappearance of unusual movements) has been far more rapid than the healing of the wound. It is curious that this fact did not suggest that continued excitation of the canals (which in the case of a wound to the canals would seem to be the case) might lead to a profound modification of the effects of ampullar stimulation." Whether the process involved in recovery after mechanical disturbance of or injury to the semicircular canals is the same as that involved in the reduction of nystagmus by means of repeated elicitation is a question which cannot be definitely answered at the present time. On a subsequent page certain experimental evidence will be cited, however, which points to a distinct difference in this respect rather than to an identity such as Griffith's comments suggest.

⁸ Cf. the observations of Bárány (7) and Wintermute (65) regarding the nystagmus of dancers who turn only in one direction and the experimental results of Abels (1) with pigeons as subjects.

to avoid a cul-de-sac in a maze. "Unless the ocular compensation [nystagmus] is useful, it simply dies out. Why not?" During bodily rotation, nystagmus is highly useful in that it automatically facilitates efficient vision; during the post-rotational period, on the other hand, nystagmus is distinctly disadvantageous in that it distorts vision and makes for spatial disorientation. (Perhaps here is one explanation for the greater reduction of the afternystagmus for the practiced than for the unpracticed direction of rotation.) This theory that nystagmus habituation may represent an adaptive, learning process, which was certainly anticipated by Abels (1) although not so explicitly stated by him as by Dodge, will be referred to again on a later page.

Holsopple (36) confirmed with human subjects the finding of Dodge (14) and others (1), (65), (7) that repeated rotation in one direction significantly diminishes the duration of the nystagmus produced by this type of stimulation but does not equally diminish the nystagmus elicited by rotation in the opposite (unpracticed) direction; and he likewise verified the observation of other investigators (43), (14), (1) that the presence of vision and the consequent possibility of fixation are not essential for the occurrence of nystagmus habituation. (Using rabbits as subjects, Maxwell and Pilz (54) have shown, in fact, that nystagmus habituation proceeds more rapidly when vision is excluded than when it is permitted.)

In a later publication, Holsopple (38) has demonstrated that the unequal reduction of after-nystagmus for the clockwise and counter-clockwise directions of rotation produced by repeated rotation in only one of these directions is probably not dependent (providing vision is excluded) upon the direction of the repeated rotation but rather upon the difference in the duration of the successive rotation (acceleration-to-retardation) and rest (retardation-to-acceleration) intervals comprising the practice schedule (Cf. Dunlap (51)). For example, if the rotation interval is relatively brief, say 10 seconds, and the rest interval relatively long, say 50 seconds, the after-nystagmus produced by rotation in the direction of practice will be more markedly reduced than the after-nystagmus produced by rotation in the opposite direc-

tion. On the other hand, if the rotation interval is relatively long, say 50 seconds, and the rest interval is relatively brief, say 10 seconds, the after-nystagmus produced by rotation in the direction of practice will be *less* markedly reduced than the after-nystagmus produced by rotation in the opposite direction. Thus, "Either type of nystagmus can be reduced by rotation in either direction depending on the distribution of time allotted to rotation and rest intervals" (38).

This discovery led Holsopple to posit the theory that "Nystagmus time decreases by virtue of having frequently run to normal completion and is *not* reduced merely because of the frequent occurrence of its stimulus." Although useful as a description of the conditions under which nystagmus habituation is most likely to occur, this statement, it should be noted, can scarcely be said to constitute an explanation of why the habituation actually occurs.

Maxwell, Burke, and Reston (52) have reported that, in rabbits, nystagmus habituation proceeds less rapidly, other conditions remaining constant, when the head is held in a fixed position with reference to the rest of the body during the rotation practice than when the head is left free. This finding was verified in an experiment by Lumpkin (47) with the same type of subject, but was contradicted by results obtained by Dorcus (15) from human subjects and by King (43) from pigeons. Whether there is thus a real difference in the way different types of subjects react to head fixation during repeated bodily rotation or whether the reported discrepancy is merely an artifact resulting from the limited number of subjects used will have to be determined by further experimentation.

Hoshino (39) has advanced the theory that the reduction of nystagmus occurring with repeated bodily rotation is due merely to fatigue, and has based this contention upon the fact that in rabbits whose nystagmus had been reduced by a single session of repeated rotation he found a considerable degree of recovery after a few hours' rest. That this recovery was probably not complete and that the effects of the one session would have summated with the effects of subsequent sessions are facts which

Hoshino entirely neglected and which are quite inconsistent with the fatigue hypothesis suggested by him.

In an experiment reported by Maxwell (55) and again in a study by Pilz (61), it was found that not only is the after-nystagmus of rabbits reduced by repeated bodily rotation but that the nystagmus occurring during rotation is also diminished, although less decidedly. "At a time when the after-nystagmus had practically disappeared, the rotation-nystagmus had not usually been reduced as much as 50 per cent. Indeed it is doubtful if the rotation-nystagmus would ever disappear under the conditions of these experiments" (53). This difference in the extent of habituation shown by the rotation and the post-rotation nystagmus may have been due to the fact that, under the conditions of the experiments just cited, the vestibular nystagmus occurring during rotation was reinforced by the movement of the visual environment in relation to the subject, whereas the vestibular nystagmus occurring during the period following rotation tended to be inhibited by the visual stimulation arising from the environment, which at this time was of course stationary with reference to the subject. In keeping with the theory that nystagmus habituation is an adaptive process, it would naturally be expected, therefore, that the post-rotational nystagmus would be more significantly modified. Or again, it may have been that the successive periods of rotation were considerably briefer than the interpolated rest periods, under which conditions, according to Holsopple's hypothesis, the post-rotational nystagmus would have been more decidedly reduced than the rotation nystagmus, quite irrespective of the visual factors. Unfortunately, neither Maxwell nor Pilz described the experimental conditions under which their respective investigations were conducted in sufficient detail to make it possible to determine whether the visual or the temporal factors (or both) were responsible for the results obtained.

Fearing (21) and King (43) have found that the nystagmus resulting from a given rotational stimulus is more prolonged in young pigeons than in older birds; but Huddleston (40) has reported exactly the opposite. Huddleston and King are agreed, however, that the nystagmus of squabs is more readily

habituated than the nystagmus of adult pigeons. King suggested that the lower susceptibility of adult birds to experimental nystagmus habituation may indicate that the repeated circling and turning involved in flying has already produced a certain amount of habituation and has therefore rendered the older birds relatively immune to further effects of this kind; but this hypothesis presupposes that adult birds actually show a significantly briefer nystagmus than do young birds, which assumption Huddleston has explicitly contradicted. It seems probable to the writer that the greater susceptibility of young birds to nystagmus habituation, if it indeed exists, is merely a manifestation of the greater adaptability and flexibility of behavior which is characteristic of all young animals.

King (43) has further reported that decerebrate (and therefore psychically blind) squabs are quite as susceptible to nystagmus reduction by means of repeated bodily rotation as are blinded but otherwise normal squabs. On the basis of this finding, King concluded that nystagmus habituation "is not of the nature of a learning process." This inference is of course based upon the assumption that learning can occur only in the cerebral hemispheres, a contention which Beritoff (8) has disproved by showing that conditioned responses may be established in entirely decerebrate pigeons. Moreover, the neurological relationship between the vestibular apparatus and the brain is such as to make the cerebellum or the brain-stem a more natural and more logical place than the cerebrum for the occurrence of whatever neural changes are involved in nystagmus habituation.

⁹ Henri and Stodel (35) have reported that the torsion of the head produced in frogs by unilateral labyrinthectomy usually disappears in about six weeks. If, however, at the end of this time, the animal is decerebrated, the original symptoms reappear and persist as long as the animal lives. Moreover, if the animal is decerebrated first and its labyrinth removed later, there is never any perceptible recovery from the effects of the latter operation. Although Henri and Stodel employed frogs as subjects in their experiments and King used pigeons, the facts revealed in these two investigations are presumptive evidence in favor of the suggestion advanced by the present writer in Note 7 that the process responsible for recovery from the effects of labyrinthine operations may be fundamentally different from the process involved in the habituation of nystagmus by means of repetition.

That the reduction of nystagmus by means of repeated elicitation is dependent upon some sort of change occurring somewhere within the central nervous system—rather than upon injury to or structural modification of the vestibular receptor mechanism—is clearly shown by investigations reported by Maxwell, Burke, and Reston (52), Gould (28), Detlefson (13), Dunlap (20), and Fearing and Mowrer (22). However, these studies have been discussed in two other papers (22), (59) and will not be further reviewed in the present report.¹⁰

Of the various investigators who have studied the effect of repeated elicitation upon the duration of vestibular nystagmus, three have reported negative findings. The first of these investigators was Prince (62), who described his experiment, in part, as follows:

Cats were subjected to interrupted horizontal rotation over a prolonged period and the nystagmus time observed. The rotation tests (20 turns in 20 seconds) were applied 50 to 60 times daily at intervals of two minutes and were repeated for twenty consecutive days.

The duration of post-rotation nystagmus under these conditions was found to vary slightly in different animals. With 20 revolutions in 20 seconds the maximal variations in the post-rotatory nystagmus times observed in six animals were from 12 to 19 seconds.

By way of summary, Prince remarks that:

The ocular responses to rotation for each animal remained fixed within narrow limits and were unaffected by prolonged rotation. It may be concluded therefore that rotation tests give an adequate index to labyrinth activity.

Whether the cat is in some way unique or whether the conditions of Prince's experiment varied in some subtle but significant way from the conditions of similar experiments with other types of subjects cannot at present be determined. The need of further

¹⁰ The effect of *continuous* rotation upon the bodily equilibrium of rats has been studied by Griffith (31) and by Dorcus (16). However, since the findings of these experimenters have only an indirect bearing upon the present discussion, they will not be reviewed here. For a discussion of the results obtained from these investigations, see Mowrer (59).

studies of nystagmus habituation with feline subjects is clearly indicated.

Although concerned with the problem of habituation in only an incidental manner, Borries (9) has reported that in pigeons "Several rotations after each other did not influence the post-rotatory nystagmus." The statements of numerous other investigators, who have also studied the effects of repeated bodily rotation in pigeons and whose findings have already been referred to, suggest that Borries' observations must either have been inaccurate or else the conditions of his experiment must have varied in some manner not indicated in his report from the experimental conditions used by other investigators.

Dorcus (17) has recently reported an experiment in which two litters of white rats (eight in all) were born and reared to the age of three months in a large cylindrical cage (3½ ft. in diameter). During the entire period of the experiment, this cage was intermittently rotated by a motor which was automatically started and stopped by a specially designed clock commutator. Each period of rotation lasted for half an hour and was followed by a rest period of one and one-half hours. The rotation was exclusively clockwise and at the rate of one revolution per second. Two weeks after the intermittent rotation had ended. Dorcus immobilized the eight rats and subjected each of them to a twenty-second period of clockwise and an equal period of counterclockwise rotation at the rate of one revolution in two seconds. On the average, these animals showed a post-rotational nystagmus for both directions slightly (though probably not significantly) higher than that reported by Griffith (30) for a group of rats not previously subjected to any passive bodily rotation whatsoever.

In order to account for this unexpected finding, Dorcus tentatively advanced the suggestion "that marked reduction does not occur in animals unless they are kept in a more or less fixed bodily position [during the practice rotation]." It is true that the majority of experimenters who have previously reported marked nystagmus habituation have immobilized their subjects during both the practice and test rotations. Abels (1) and Griffith (3), however, are exceptions in that they allowed their subjects

(pigeons and rats, respectively) complete freedom within a small cage during all periods of rotation; and, it will be recalled, both of these investigators reported virtually complete abolition of the nystagmus of their subjects. Since Dorcus' rats were practiced under rotational conditions somewhat dissimilar to those employed in the subsequent nystagmus test, it is possible that some variation between the two sets of conditions—for example. difference in the duration or velocity of rotation or in the rate of acceleration and retardation—may have been responsible for the observed absence of the habituation effect.¹¹ Or, again, it may have been that the post-rotational nystagmus shown by Dorcus' subjects under the test conditions was increased, and the habituation effect of the previous rotation therefore masked, by the fact that these animals were unaccustomed to being handled or immobilized and were consequently probably highly excited and unusually responsive. Such an explanation is at least suggested by the finding, recently reported by the writer (56), that both naïve and habituated pigeons usually show a considerably longer postrotational nystagmus when tested immediately after being handled and excited than when hooded and immobilized and allowed to remain undisturbed in a quiet room for twenty minutes before being tested.

Although the negative findings of Prince, Borries, and Dorcus, which have been discussed in the immediately preceding pages, do not in any sense prove that vestibular nystagmus may not, under certain conditions, be considerably reduced or even abolished by repeated elicitation, they do, however, clearly show that this response is not *invariably* diminished by repetition. More complete information than is now available regarding the particular circumstances under which nystagmus reduction does and does not occur is therefore obviously needed before any definite conclusion may be drawn regarding the exact nature of the

¹¹ Griffith (30) has remarked in this connection that "It must be emphasized that any decrease [in the post-rotational nystagmus times of rats] is for one set of conditions only.... Changing the speed or the number of rotations at any time produced a similar reappearance of nystagmus, but never in its original intensity or temporal duration."

process specifically responsible for this type of response modification.¹²

V. PROCEDURE AND RESULTS

The experiments reviewed in the preceding sections of this paper indicate that a variety of factors—presence or absence of vision, direction of rotation, emotional disturbance, relative duration of the successive rotation and rest intervals, fixation or non-fixation of the head, age and type of subject, etc., may be influential in determining the rate and extent of the nystagmus reduction produced by any given schedule of repeated bodily rotation. It is not surprising, therefore, that the results reported by different investigators have frequently involved apparent contradictions and inconsistencies. No less understandable is the lack of agreement existing among the various writers regarding the probable explanation of nystagmus habituation. In the hope of somewhat clarifying rather than merely increasing this confusion, the writer has undertaken a series of habituation experiments in which an attempt has been made to hold constant all conceivably significant factors, except some single factor which is varied, in each experiment, in a controlled manner. The writer readily concedes that the results obtained from the present investigation still leave unsolved many of the problems discussed in the foregoing pages, although perhaps certain questions have been answered with a fair degree of finality and a few previously unanticipated facts brought to light.

The rotation apparatus used in the present investigation is pictured in plate 1. The *driving unit* is merely a modified form of the device previously described by Dunlap (19) and will not be discussed here except to mention that the starting and stopping of the rotation unit were accomplished by the use of electro-

¹² In a recent publication, Lorente de Nó (44) has briefly discussed nystagmus habituation and has referred to experimental results reported in two earlier papers (one by himself and the other by A. Malan), which, however, have not been accessible to the writer and for this reason are not cited in the present review. Fischer (23) has also alluded to this topic, with the comment that the process involved in nystagmus habituation is probably a "central phenomenon," but has presented no original experimental data.

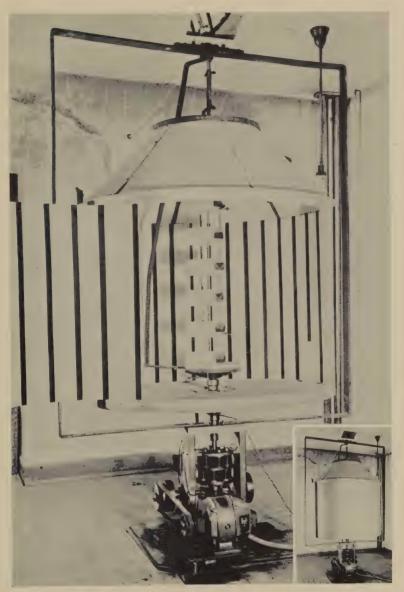


PLATE 1

magnetic clutches rather than by merely starting and stopping the electric motor. The rotation unit consisted of two distinct parts: (a) a large cylinder four feet in diameter and approximately four feet high and (b) a multiple holder capable of accommodating six subjects simultaneously (see plate 2). The cylinder and the holder could each be rotated in either direction with the other at rest, or both could be rotated together in either direction. The light gray interior of the cylinder was well illuminated and was variegated by vertical black stripes one inch wide and four inches apart. Whenever the cylinder was rotated alone or in conjunction with the holder, the door in the side of the cylinder was closed, as shown in the insert in the lower right-hand corner of plate 1, and all visual stimulation from the experimental room thereby excluded save for an insignificant amount of light entering the cylinder from the relatively small opening in the top of the conical cover. A mirror placed at a suitable angle about eighteen inches above this opening made it possible for the experimenter to observe the subjects at all times under these conditions. clamp, suitable for holding a 16 mm. motion picture camera was mounted immediately above the cylinder and was articulated with the platform, upon which the multiple holder was fastened. in such a way as to cause the camera to rotate concurrently with the platform, or, if the platform were at rest, to remain at rest, uninfluenced by movement of the cylinder. (When motion pictures were to be made, the multiple holder was replaced by a holder accommodating a single subject.)

Partly because of the frequent use made of them in previous studies of this kind and partly because of other reasons, such as convenience in keeping and handling, pigeons were selected as subjects for this investigation. Common adult birds were used in all of the experiments and, when not being actually experimented with, were kept in a large outdoor cage which provided an opportunity for abundant exercise and generally healthful living conditions.

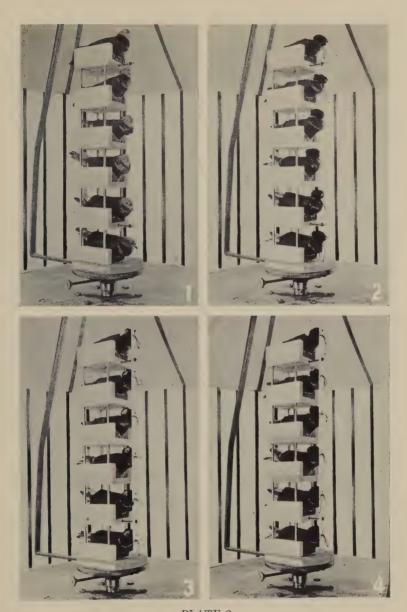


PLATE 2

Series A

The first series of experiments, undertaken primarily as a preliminary study, was commenced on March 9 and involved the use of twenty-four subjects. On this date each bird was given a standard test for vestibular nystagmus for both the clockwise and counter-clockwise directions. The clockwise and the counter-clockwise rotation periods both consisted of fifteen turns in thirty seconds and were separated, for each bird, by approximately half an hour; acceleration and retardation each occupied about 0.5 seconds for both directions of rotation. The post-rotational nystagmus, which was recorded with a split-second stop-watch, was timed from the onset of retardation to the last nystagmic head movement. The nystagmus times obtained from the twenty-four subjects for the clockwise and counter-clockwise directions of turning are given in appropriately designated columns in table 1.

The birds were then divided by random selection into eight groups of three birds each. Beginning on March 10, each of these groups was subjected to a schedule of repeated daily rotation under the various conditions indicated by the legends in the two columns at the left in table 1. Each daily experimental session consisted of six periods of rotation, each period being comprised of fifteen turns in thirty seconds with interpolated rest period of equal duration.

At the end of 32 days, the habituation routine was discontinued; and each bird was tested for post-rotational vestibular nystagmus in exactly the same manner as before the habituation was commenced. The nystagmus times thus obtained for each of the 24 birds for the clockwise and counter-clockwise directions are given in table 1. In the two extreme right-hand columns of table 1 are also given the *percentage* of change between the original and final post-rotational nystagmus time of each bird for both the clockwise and counter-clockwise directions. The plus (+) or minus (-) sign in front of each entry in these two columns indicates whether this change was of the nature of an increase or a decrease.

It is apparent from the results thus represented in table 1 that the most striking reduction in vestibular nystagmus was produced

TABLE 1
Original and final post-rotational nystagmus times of 24 pigeons and percentage of change produced by 32 days of habituation to various conditions of rotation

Rotation of body only. Vision permitted Rotation of body only. Vision permitted	Rotation alternately clockwise and counter-clockwise Rotation in clockwise direction only Rotation alternately clockwise and counter-clockwise Rotation in clockwise direction only	Avera	MARC CW seconds 24.8 24.8 24.8 24.8 28.0 22.8 27.2 26.4 27.0 31.0 19.0	CCW seconds 20.6 28.8 25.0 24.2 20.4 32.2 21.6 19.2 21.2	17.6 21.8 22.4	CCW seconds 5.6 12.2 10.6 8.8 7.4 11.2 20.8 19.6 23.4	CHA CW per cent83 -55 -35 -64 -69 -67 -44 -60 -22 -17 -17	CCW per cent73 -58 -58 -63 -64 -64 -65 -64 +02 +10 +03
Rotation of body only. Vision permitted Rotation of body only. Vision permitted	nately clock- wise and count- er-clockwise Rotation in clock- wise direction only Rotation alter- nately clock- wise and count- er-clockwise Rotation in clock- wise direction	1 Avera 2 Avera 3	24.8 24.8 24.8 24.8 24.8 24.8 24.8 27.2 28.0 22.8 27.2 26.4 27.0 31.0 19.0	24.2 20.4 32.2 21.6 19.2 21.2	8.6 7.6 15.4 17.6 21.8 22.4	8.8 7.4 11.2 20.8 19.6 23.4		per cent73 -58 -58 -63 -64 -65 -64 +02 +10
Rotation of body only. Vision permitted Rotation of body only. Vision permitted	nately clock- wise and count- er-clockwise Rotation in clock- wise direction only Rotation alter- nately clock- wise and count- er-clockwise Rotation in clock- wise direction	Avera Avera	24.8 24.8 24.8 24.8 22.8 27.2 age 22.4 26.4 27.0 age	20.6 28.8 25.0 24.2 20.4 32.2 21.6 19.2 21.2	4.2 11.2 11.2 11.2 	5.6 12.2 10.6 8.8 7.4 11.2 20.8 19.6 23.4	-60 -22 -17 -17	-64 -64 -65 -64 -04 +02 +10
Rotation of body only. Vision permitted Rotation of body only. Vision permitted	nately clock- wise and count- er-clockwise Rotation in clock- wise direction only Rotation alter- nately clock- wise and count- er-clockwise Rotation in clock- wise direction	Avera Avera	24.8 24.8 age 28.0 22.8 27.2 age 26.4 27.0 age 31.0 19.0	28.8 25.0 24.2 20.4 32.2 21.6 19.2 21.2	11.2 11.2 11.2 8.6 7.6 15.4 17.6 21.8 22.4	12.2 10.6 8.8 7.4 11.2 20.8 19.6 23.4	-83 -55 -35 -64 -69 -67 -44 -60 -22 -17 -17	$ \begin{array}{r} -73 \\ -58 \\ -58 \end{array} $ $ \begin{array}{r} -63 \\ -64 \\ -65 \end{array} $ $ \begin{array}{r} -64 \\ -45 \\ \end{array} $ $ \begin{array}{r} -64 \\ \end{array} $
Rotation of body only. Vision permitted Rotation of body only. Vision permitted	wise and count- er-clockwise Rotation in clock- wise direction only Rotation alter- nately clock- wise and count- er-clockwise Rotation in clock- wise direction	Avera	24.8 age 28.0 22.8 27.2 age 26.4 27.0 age 31.0 19.0	25.0 24.2 20.4 32.2 21.6 19.2 21.2	11.2 8.6 7.6 15.4 17.6 21.8 22.4	8.8 7.4 11.2 20.8 19.6 23.4	$ \begin{array}{r} -35 \\ -64 \\ \hline -69 \\ -67 \\ -44 \\ \hline -60 \\ \hline -22 \\ -17 \\ -17 \\ \end{array} $	$ \begin{array}{r} -58 \\ -58 \\ \hline -63 \\ \hline -64 \\ -65 \\ \hline -64 \\ \hline -04 \\ +02 \\ +10 \\ \end{array} $
Rotation of body only. Vision permitted Rotation of body and environment	Rotation in clock- wise direction only Rotation alter- nately clock- wise and count- er-clockwise Rotation in clock- wise direction	Avera	28.0 22.8 27.2 age 26.4 27.0 age 31.0 19.0	24.2 20.4 32.2 21.6 19.2 21.2	8.6 7.6 15.4 17.6 21.8 22.4	8.8 7.4 11.2 20.8 19.6 23.4	$ \begin{array}{r} -64 \\ -69 \\ -67 \\ -44 \\ \hline -60 \\ \hline -22 \\ -17 \\ -17 \\ \end{array} $	$ \begin{array}{r} -63 \\ -64 \\ -64 \\ -65 \\ \end{array} $ $ \begin{array}{r} -64 \\ -04 \\ +02 \\ +10 \\ \end{array} $
Rotation of body only. Vision permitted Rotation of body and environment	Rotation in clock- wise direction only Rotation alter- nately clock- wise and count- er-clockwise Rotation in clock- wise direction	Avera	28.0 22.8 27.2 age 26.4 27.0 age 31.0 19.0	24.2 20.4 32.2 21.6 19.2 21.2	8.6 7.6 15.4 17.6 21.8 22.4	8.8 7.4 11.2 20.8 19.6 23.4	-69 -67 -44 -60 -22 -17 -17	$ \begin{array}{r} -64 \\ -64 \\ -65 \\ \hline -64 \\ -04 \\ +02 \\ +10 \\ \end{array} $
Rotation of body only. Vision permitted Rotation of body and environment	Rotation alternately clockwise and counter-clockwise Rotation in clockwise direction	Avera 3 Avera	22.8 27.2 age 22.4 26.4 27.0 age 31.0 19.0	20.4 32.2 21.6 19.2 21.2	7.6 15.4 17.6 21.8 22.4	7.4 11.2 20.8 19.6 23.4	$ \begin{array}{r} -67 \\ -44 \\ \hline -60 \\ \hline -22 \\ -17 \\ -17 \\ \end{array} $	$ \begin{array}{r} -64 \\ -65 \\ \end{array} $ $ \begin{array}{r} -64 \\ +02 \\ +10 \\ \end{array} $
Rotation of body only. Vision permitted Rotation of body and environment	Rotation alternately clockwise and counter-clockwise Rotation in clockwise direction	Avera 3 Avera	22.8 27.2 age 22.4 26.4 27.0 age 31.0 19.0	20.4 32.2 21.6 19.2 21.2	7.6 15.4 17.6 21.8 22.4	7.4 11.2 20.8 19.6 23.4	$ \begin{array}{r} -67 \\ -44 \\ \hline -60 \\ \hline -22 \\ -17 \\ -17 \\ \end{array} $	$ \begin{array}{r} -64 \\ -65 \\ \end{array} $ $ \begin{array}{r} -64 \\ +02 \\ +10 \\ \end{array} $
Rotation of body and environment	Rotation alternately clockwise and counter-clockwise Rotation in clockwise direction	3 Avera	27.2 27.2 age 22.4 26.4 27.0 age 31.0 19.0	32.2 21.6 19.2 21.2	17.6 21.8 22.4	20.8 19.6 23.4	$ \begin{array}{c c} -44 \\ \hline -60 \\ \hline -22 \\ -17 \\ -17 \\ \end{array} $	$ \begin{array}{r} -65 \\ \hline -64 \\ \hline +02 \\ +10 \end{array} $
Rotation of body and environment	nately clock- wise and count- er-clockwise Rotation in clock- wise direction	3 Avera	22.4 26.4 27.0 age 31.0 19.0	21.6 19.2 21.2	17.6 21.8 22.4	20.8 19.6 23.4	-22 -17 -17	$ \begin{array}{r} -04 \\ +02 \\ +10 \end{array} $
Rotation of body and environment	nately clock- wise and count- er-clockwise Rotation in clock- wise direction	Avera	26.4 27.0 age	19.2	21.8 22.4	19.6 23.4	-17 -17	+02 +10
Rotation of body and environment	nately clock- wise and count- er-clockwise Rotation in clock- wise direction	Avera	26.4 27.0 age	19.2	21.8 22.4	19.6 23.4	-17 -17	+02 +10
Rotation of body and environment	wise and count- er-clockwise Rotation in clock- wise direction		27.0 age	21.2	22.4	23.4	-17	+10
Rotation of body and environment	er-clockwise Rotation in clockwise direction		31.0 19.0					
Rotation of body and environment	wise direction		31.0				-19	+03
Rotation of body and environment	wise direction	4	19.0	27.8				100
body and environ- ment					26.8	18.8	-14	-32
body and environ- ment	only			20.2	30.1	21.6	+58	+07
body and environ- ment			27.4	25.0	33.6	24.8	+23	-01
body and environ- ment		Avera	age				+22	-09
environ- ment	Rotation alter-	5	19.0	19.6	10.4	10.0	-45	-49
ment	nately clock-		17.0	18.6	12.0	8.2	-29	-50
	wise and count-		35.0	24.6	29.8	20.6	-14	-16
	er-clockwise	Avera	age				-29	-38
	Rotation in clock-	6	36.2	32.2	33.6	24.8	-07	-23
	wise direction		25.8	23.0	16.6	10.6	-36	-54
	only		26.4	22.2	22.0	12.2	-17	-45
		Avera	age				-20	-41
Rotation of	Rotation alter-	7	29.2	29.4	22.0	17.0	-25	-42
environ-	nately clock-		19.6	18.2	16.4	17.8	-16	-02
ment only	wise and count-		24.0	19.8	21.8		-09	+24
	er-clockwise	Avera	age				-17	-07
	Rotation in clock-	8	27.0	26.0	29.6	19.4	+10	-25
	wise direction		26.6	27.8	24.6	16.4	-08	-41
	anles	-	19.0	27.4	16.8	14.8	-12	-4 6
	only						-03	-37

in Groups 1 and 2, i.e., in those birds subjected to actual bodily rotation with vision eliminated. It will also be noted that under these conditions the reductions produced in the clockwise and the counter-clockwise post-rotational nystagmus by practice in the clockwise direction only are equal and that the same is also true of the reductions produced by practice alternately in the clockwise and counter-clockwise directions. Moreover, it is to be noted that these two sets of reductions are also equal to each other.

The results produced by the repeated rotation of Groups 3 and 4, with vision permitted, indicate, despite considerable irregularity in particular instances, that little or no real reduction in the purely vestibular nystagmus has been produced by either the exclusively clockwise or alternately clockwise and counter-clockwise rotation practice. This finding, more clearly portrayed by subsequent experiments, was wholly unexpected and has presumably not been previously reported.

The repeated rotation of the birds in both Group 5 and Group 6 seemed to have a tendency to reduce the counter-clockwise afternystagmus more than the clockwise after-nystagmus. However, as later experiments will show, this tendency was due merely to chance variables.

The difference in the amount of reduction shown by the birds in Group 7 for the clockwise and counter-clockwise directions is, again, probably not reliable. However, the difference shown in this respect by the birds in Group 8 is reliable, as will be brought out in a later series.

The results obtained from this preliminary series of experiments made it evident that in future experiments the testing procedure would have to be altered so as to increase the reliability of the nystagmic measures. Certain expedients were adopted in this connection which will be made apparent in the description of the following series of experiments.

Series B

In this series of experiments, 24 previously unrotated pigeons were tested, on April 18, for clockwise and counter-clockwise

post-rotational nystagmus in exactly the same manner as in the preceding experiment except that the rate of rotation used was one revolution in one and one-half seconds instead of one revolution in two seconds. Then on April 19, the birds were all again tested in the same manner, except that they were rotated in the

TABLE 2

Post-rotational nystagmus times of 24 previously unrotated pigeons (Series B)

CROTTE		CLOCKWISE	COUNTER-CLOCKWISE			
GROUP	April 18	April 19	Average	April 18	April 19	Average
	seconds	seconds	seconds	seconds	seconds	seconds
	23.0	24.6	23.8	17.6	27.8	22.7
	21.8	25.8	23.8	22.8	23.6	23.2
1	21.4	23.8	22.6	20.8	23.0	21.9
1	21.6	24.0	22.8	22.0	21.2	21.6
	24.2	19.8	22.0	15.6	33.6	24.6
	20.4	18.6	19.6	20.2	23.0	21.6
.(28.4	28.6	28.5	23.2	24.4	23.8
	15.8	21.2	18.5	13.4	23.6	18.3
2	19.8	20.8	20.3	14.0	20.6	17.3
2	28.2	25.0	26.6	19.6	27.0	23.3
	18.0	24.4	21.2	17.2	23.4	20.3
l	21.2	26.8	24.0	17.6	27.8	22.7
(23.8	31.2	27.5	11.6	28.4	20.0
	23.4	32.8	28.1	16.0	35.0	25.5
3	37.8	33.6	35.7	33.6	34.0	33.8
3	11.4	15.6	13.5	10.2	19.8	15.0
	30.0	21.8	25.9	24.8	27.4	26.1
(27.4	28.4	27.9	26.6	24.4	25.5
(22.0	23.8	22.9	26.4	22.0	24.2
	29.4	21.0	25.2	25.4	24.8	25.1
	21.6	20.0	20.8	18.4	26.8	22.6
4 {	24.8	30.6	27.7	25.0	23.6	25.3
	18.0	20.2	19.1	15.0	17.0	16.0
	27.0	37.4	32.2	15.0	27.4	21.2

counter-clockwise direction first and then in the clockwise direction rather than in the reverse order. The nystagmus times obtained on these four individual rotation tests and the average nystagmus time for each bird for the two clockwise and two counter-clockwise tests are given in table 2.

TABLE 3

Percentage of change in the post-rotational nystagmus times of 24 pigeons after 24 and after 36 days of habituation to repeated rotation under the conditions indicated by the legends in the left-hand column

		24-DA	Y TEST	36-day test		
	GROUP	CW	CCW	CW	CCW	
Rotation of body only.	1	per cent67 -70	per cent38 -42	,	per cent49 cme ill)	
Vision ex- cluded		-66 -51 -71 -49	-55 -55 -67 -51	-63 -54 -37 -49	$ \begin{array}{r} -60 \\ -40 \\ -09 \\ -52 \end{array} $	
	Average	-62	-55	-50	-42	
Rotation of body only. Vision permitted	2	$ \begin{array}{r} -12 \\ +12 \\ 00 \\ -29 \\ +20 \\ +25 \end{array} $	+19 +25 +40 -40 -12 -23	+06 +49 -21 -20 +24 +28	+33 +42 -13 -13 -05 -31	
	Average	+03	+02	+02	+02	
Rotation of body and environment	3	-27 -37 -53 00 -19 +05	+17 -24 -37 +25 -38 -08	-20 -20 -25 -07 -04 -28	+18 -17 -38 +22 -21 -18	
٠.	Average	-22	-11	-17	-09	
Rotation of environment only	4	-13 +12 -13 +10 +01 +09	$ \begin{array}{r} -35 \\ -22 \\ -25 \\ -11 \\ -09 \\ +04 \end{array} $	$ \begin{array}{r} -07 \\ -04 \\ -09 \\ -01 \\ +14 \\ +04 \end{array} $	$ \begin{array}{r} -32 \\ -34 \\ \hline +23 \\ -19 \\ -09 \\ -01 \end{array} $	
	Average	+01	-16	-01	-20	

These 24 birds were then arbitrarily divided into four groups of six birds each. Beginning on April 20, each of these four groups was daily subjected to ten periods of rotation under one of the four conditions indicated by the legends in the left-hand column of table 3. The speed of the practice rotation was the same as used in the testing of these birds, namely, one revolution in one and one-half seconds; and the successive rotation periods lasted 30 seconds, with interpolated rest periods of the same duration. Groups 1, 2, and 3 were practiced only in the clockwise direction. In the case of Group 4, however, the environment was rotated exclusively in the counter-clockwise direction.

At the end of 24 days of practice rotation, each of the 24 birds comprising the four groups just described was tested for vestibular nystagmus in exactly the same manner as before the habituation had been commenced. The percentage of change in the clockwise and counter-clockwise nystagmus time for each bird is given in the two columns, headed "24-day test," in table 3.

Immediately following this first re-test, the four groups of pigeons were subjected to twelve days of further habituation under the same conditions as those to which they had formerly been subjected. A second re-test, following this second period of habituation, indicated that no consistent change had been produced by the additional habituation, but afforded verification of the reliability of the results obtained on the first re-test (see the two columns, headed "36-day test," in table 3).

The nystagmus reduction produced in Group 1 of the present series, it will be noted, is quite comparable to the reduction produced under similar conditions in Group 2 in Series A. On the basis of these combined findings, it may be concluded that repeated bodily rotation in only one direction, with vision excluded and with the successive periods of rotation and rest of equal duration, produces an equal reduction in the duration of the after-nystagmus elicited by bodily rotation in both the clockwise and in the counter-clockwise directions. It is further evident that an average reduction of about 60 per cent in the duration of the post-rotational nystagmus is probably the maximal effect which can be produced under the conditions just described.

The results obtained from Group 2 in the present series confirm the results obtained from Groups 3 and 4 in Series A: repeated bodily rotation under the conditions of the present series, with vision permitted, produces no reduction whatever in the duration of the nystagmus elicited by bodily rotation with vision excluded.

The birds in Group 3 showed a relatively greater reduction in post-rotational nystagmus for the direction of practice than for the opposite direction of rotation. However, since the amount of difference here is slight and since exactly the opposite tendency was observed in the results obtained from Group 6 in Series A, it seems probable that the differences noted in the two instances were entirely non-significant, that is to say, that the reduction of purely vestibular nystagmus which is produced by repeated rotation of the subject and environment simultaneously is about equal for both the clockwise and counter-clockwise after-nystagmus and is, furthermore, considerably less pronounced than the reduction produced by repeated bodily rotation with vision eliminated.¹³

The results obtained from the six birds in Group 4 reveal that the repeated rotation of the environment in the counter-clockwise direction produces no noticeable modification in the vestibular after-nystagmus for the clockwise direction of bodily rotation but does produce a slight and fairly consistent reduction in the after-nystagmus for the counter-clockwise direction of rotation. That this differential effect is reliable is further indicated by the fact that strictly comparable results were obtained from the three birds in Group 8 in Series A. In passing, it may be pointed out that the nystagmus elicited by counter-clockwise rotation of the environment is identical, as regards the respective directions of the

¹³ It should be mentioned at this point that it was impossible to accelerate or retard the cylinder comprising the artificial environment of the rotation apparatus used in the present investigation in less than five seconds. Since this slower rate of acceleration and retardation was unavoidably used in the repeated rotation of the birds in Groups 5 and 6 in Series A and in Group 3 in the present series, it is impossible, therefore, to make a close comparison of the habituation effects thereby produced with the habituation effects produced by the rotation of subjects with the environment stationary.

slow and quick components of the response, with the vestibular after-nystagmus elicited by counter-clockwise bodily rotation. This fact is in some way responsible, no doubt, for the results just cited; but it is impossible at the present time to determine the exact manner in which the observed effects were produced.

Series C

In this series, 24 previously unrotated pigeons were tested for vestibular after-nystagmus on two successive days, May 16 and 17, in exactly the same manner as described for the 24 birds used The nystagmus time for each bird for the four in Series B. periods of rotation and the average nystagmus time for the two clockwise and two counter-clockwise periods are given in table 4. Again the 24 birds were divided into four equal groups. birds in Group 1 of this series were subjected to the same general routine of repeated bodily rotation as was used in Series B. with this variation, however, that the head of each bird was held in a fixed position with reference to the rest of the bird's body during the repeated rotation (see illustration 4 in plate 2). Moreover, vision was uniformly excluded throughout the rotation practice. Under these conditions there was a decided and roughly equal reduction for both the clockwise and the counter-clockwise afternystagmus, as indicated in table 5.

Group 2 in this series was subjected to the same schedule of repeated rotation as Group 1, also with head fixed, but with vision permitted (see illustration 3 in plate 2). Under these conditions there was a conspicuous reduction in the clockwise after-nystagmus but no significant change in the counter-clockwise after-nystagmus.

The birds in Group 3 were subjected to the repeated rotation with the head free and vision excluded, but were unique in that they were rotated for only 6 seconds and rested for 54 seconds instead of being rotated and rested for equal intervals of 30 seconds, as were all previous groups. The results for this group are given in table 5 and confirm Holsopple's contention that the relative duration of the rotation and rest intervals is an important factor in determining whether the clockwise or counter-clockwise

after-nystagmus will be the more markedly reduced by rotation practice in a given direction.

The birds in Group 4 were subjected to the same experimental conditions as the birds in Group 3, except that they were rotated

TABLE 4

Post-rotational nystagmus times of 24 previously unrotated pigeons (Series C)

GROUP		CLOCKWISE		· cor	NTER-CLOCKW	ISE
GROUP	May 16	May 17	Average	May 16	May 17	Average
,	seconds	seconds	seconds	seconds	seconds	seconds
(26.4	18.0	22.2	21.6	19.2	20.4
	19.2	16.2	17.7	15.6	20.2	17.9
1 {	15.6	23.8	19.7	12.8	35.0	23.9
	21.0	19.0	20.0	18.6	19.8	19.2
	21.4	19.6	20.5	19.0	20.0	19.5
28.8	27.2	28.0	23.0	34.0	28.5	
(24.8	27.6	26.2	17.8	22.0	19.9
	37.0	34.6	36.8	37.8	41.0	39.4
2	21.8	19.4	20.6	14.4	14.2	14.3
	24.4	24.6	24.5	28.0	25.0	26.5
	27.2	22.0	24.6	28.0	28.0	28.0
(11.8	19.4	15.6	14.8	19.2	17.0
28.0	28.0	22.2	25.1	18.6	20.0	19.3
	29.4	24.4	26.9	26.2	23.8	25.0
3	31.6	. 31.8	31.7	27.2	31.6	29.4
9	26.0	26.8	26.4	22.8	17.6	20.2
	26.4	29.2	27.8	23.0	20.8	21.9
,	41.0	39.0	40.0	37.2	34.4	35.8
(22.2	20.0	21.1	20.4	21.8	21.1
	19.6	20.6	20.1	22.0	19.6	20.8
4	17.0	24.4	20.7	16.6	20.4	18.5
1	27.6	24.4	26.0	29.6	37.2	33.4
	29.8	28.6	29.2	22.8	26.4	24.6
	26.0	30.6	28.3	29.0	31.8	30.4

for 54 seconds and rested only 6 seconds. Under these conditions, it will be noted from the results presented in table 5, that the reduction of the clockwise and counter-clockwise post-rotational nystagmus is about equal. According to Holsopple's hypothesis, the counter-clockwise after-nystagmus should have been more

TABLE 5

Percentage of change in the post-rotational nystagmus times of 24 pigeons after 24

and after 36 days of habituation to repeated rotation under the conditions indicated by the legends in the left-hand column

		24-DA	TEST	36-DAY TEST		
	GROUP	CW	CCW	CW	CCW	
		per cent.	per cent.	per cent.	per cent.	
Head fixed.	1	-64	-49	-60	-50	
Vision ex-		-34	-23	-16	-05	
cluded		-32	-32	-22	-25	
		-25	-24	+09	+09	
		-74	-64	-51	-51	
		-64	-36	-35	-34	
	Average	-47	-38	-29	-26	
Head fixed.	2	00	+24	-58	+40	
Vision per-		-67	00	-66	-02	
mitted		-58	+22	-65	-12	
		-19	+05	-59	-24	
		-58	-15	-54	-35	
		-23	+11	-38	+02	
	Average	-38	-08	-57	-05	
Rotation-rest	3	-65	+02	-39	-25	
ratio: 6 sec-		-28	-12	-34	-32	
onds: 54 sec-		-54	-26	-28	-27	
onds		-31	+18	-28	+19	
		-44	-08	-18	+05	
		-40	-31	-36	-13	
	Average	-44	-10	-31	-12	
Rotation-rest	4	-60	-56	-52	-51	
ratio: 54 sec-		-15	-43	-27	-29	
onds: 6 sec-		-24	-11	-20	-04	
onds		(Esc	aped)			
	Antanapa	-49	-47	-45	-33	
		-53	-60	-41	-61	
	Average	-40	-43	-37	-40	

markedly reduced in consequence of this practice schedule than the clockwise after-nystagmus. The probable reason why this did not occur is that, although the clockwise after-nystagmus was prevented from "running to normal completion" during the successive periods of rotation within a given session, this response was unavoidably permitted to run to "normal to completion" once at the end of each session. It is quite likely, therefore, that if the clockwise and counter-clockwise after-nystagmus of the birds in this group had been tested, say, at the end of five or six days' practice, the counter-clockwise after-nystagmus would have shown an appreciably greater reduction than the clockwise after-nystagmus. However, since the nystagmus was not tested until after 24 days of habituation, it may be assumed that, by virtue of the unavoidable situation just referred to, the clockwise as well as the counter-clockwise after-nystagmus had been permitted to run their full course sufficiently often for them both to have reached maximum habituation for the given conditions.

In addition to the results which have already been described, certain incidental observations were made which seem worth reporting. In Series A motion picture records were made of both the rotational and post-rotational nystagmus of certain birds in Groups 1 and 2, both before and after the habituation period. These records showed that the rotational and post-rotational nystagmus for both the clockwise and counter-clockwise directions were equally reduced by the conditions of rotation practice to which the birds in these two groups were subjected. This finding is in opposition to the findings of Maxwell (53) and of Pilz (61) which were mentioned on a previous page. As suggested at that time, the presence of vision during the habituation experiments of these latter investigators was probably responsible for the difference in the degree of reduction observed by them in the nystagmus occurring during rotation and in the so-called after-nystagmus.

Careful observation of the birds comprising Groups 3 and 4 in Series A and Group 2 in Series B revealed that when pigeons are rotated with vision permitted, there is a vigorous nystagmus during the entire period of rotation with little or no after-nystagmus when rotation is ended (cf. Mowrer (58)). It was further observed that these relations were not noticeably altered by extensive repetition.

Motion pictures were made of some of the birds in Groups 5 and 6 in Series A, which were subjected to the repeated bodily rotation with the environment rotating concurrently. These motion picture records showed that at the onset of the practice rotation, there was usually a conspicuous though brief nystagmus produced by acceleration and a comparable nystagmus produced by retardation. As the practice rotation proceeded, however, both of these responses gradually disappeared. This finding was confirmed by direct observation of the birds comprising Group 3 in Series B.

At the onset of the habituation of the birds in Groups 7 and 8 in Series A and Group 4 in Series B, it was frequently noted that the nystagmus elicited by the rotation of the environment often persisted for four or five seconds after the environment had been brought to complete rest. This persistence of visually elicited nystagmus after the stopping of the environment has been dealt with independently in another paper (57) and need not be discussed here except to mention that this type of after-response gradually disappeared as the repeated rotation of the environment was continued from day to day. There was, however, no noticeable weakening in the nystagmus elicited during the actual rotation of the environment.

VI. SUMMARY

Previous investigations have been reviewed which indicate that the nystagmus produced by bodily rotation may often be significantly reduced, in both duration and magnitude, by means of repeated elicitation. An analysis of the experimental conditions employed by the various investigators in this field has revealed that a variety of factors may be influential in determining the rate and extent of nystagmus reduction produced by any given schedule of repeated rotation. Different investigators have allowed these factors to operate in their respective experiments in a wide variety of controlled (and uncontrolled) ways, with the

result that inconsistencies and contradictions in previously published data have frequently obscured genuine cause-and-effect relationships and have made an understanding of this "habituation" phenomenon and the conditions conducive to its occurrence extremely difficult.

Conspicuous among the reasons for this confused state of affairs is the failure of certain writers to differentiate clearly between vestibular nustaamus, i.e., nystagmus produced by angular acceleration or retardation, or by certain other physical agencies (notably heat and electricity) which are known to have a stimulating effect upon the sense organs of the non-acoustic labyrinth, and visual nystagmus, i.e., nystagmus produced by movement of the visual environment with reference to the subject or by movement of the subject with reference to the visual environment. Both of these types of nystagmus are identical in that they consist of an oscillatory pattern of head or (in some species, including human beings) eye movements, involving a slow, "compensatory" drift in one direction alternating with a quick, "saccadic" response in the opposite direction. Under ordinary biological conditions. the reflexes responsible for vestibular and visual nystagmus function harmoniously and complementarily; but under experimental conditions, these two types of response tendency are often mutually antagonistic. In any attempt to analyse the conditions and factors favoring the habituation of the nystagmus occurring either during or after bodily rotation, it is therefore highly imperative that the visual and vestibular elements involved in any given experimental situation should be fully recognized and controlled.

Another point which must be taken into full account is that for any given plane of head (or eye) movement, there can be two and only two patterns of nystagmic response, regardless of whether the reactions are elicited by visual or by vestibular stimulation alone or in combination. Thus, in the case of horizontal nystagmus, there may be a nystagmus to the right or a nystagmus to the left, the particular designation depending, by arbitrary agreement, upon the direction of the quick component of the response with reference to the subject. The vestibular

nystagmus produced by bodily acceleration in the clockwise direction and by retardation in the counter-clockwise direction is, in this conventionally accepted terminology, a nystagmus to the right; and, conversely, the vestibular nystagmus produced by bodily acceleration in the counter-clockwise direction and by retardation in the clockwise directions is a nystagmus to the left. Likewise, the visual nystagmus produced by rotation of the visual environment in the counter-clockwise direction (to the left) with reference to the subject or by rotation of the subject in clockwise direction with reference to the environment is a nystagmus to the right; and, conversely, the visual nystagmus produced by rotation of the visual environment in the clockwise direction (to the right) with reference to the subject and by rotation of the subject in the counter-clockwise direction with reference to the environment is a nystagmus to the left.

With the foregoing relationships and definitions presupposed, the conclusions summarily stated below and based upon a series of habituation experiments described in the preceding section of this paper seems justifiable, it being understood, however, that these conclusions are not necessarily valid for any type of subject other than the type used in this investigation (namely, pigeons) and that all use of the term *nystagmus* will refer exclusively to head nystagmus, in the horizontal plane.

- 1. With the subject's vision excluded and the successive rotation and rest intervals of equal and fairly long duration, repeated bodily rotation in either the clockwise or counter-clockwise direction or alternately in both directions may be relied upon to produce a substantial and equal diminution in both the rotational (acceleration) and post-rotational (retardation) vestibular nystagmus for both directions of turning.
- 2. If the conditions described in 1 are varied so as to make the rest (retardation-to-acceleration) interval longer than the rotation (acceleration-to-retardation) interval, repeated bodily rotation in a given direction tends to produce a greater reduction in the post-rotational nystagmus for the direction of practice (and in the rotational nystagmus for the unpracticed direction) than in the post-rotational nystagmus for the unpracticed direction (and

in the rotational nystagmus for the practiced direction). (This statement is probably true only within limits: thus, if the duration of the successive periods of rotation equals or exceeds the duration of the rotational nystagmus, the differential effect just described cannot be expected to occur.)

- 3. If, on the other hand, the conditions described in 1 are varied so as to make the rotation interval longer than the rest interval, repeated bodily rotation in a given direction tends to produce a smaller reduction in the post-rotational nystagmus for the direction of practice (and in the rotational nystagmus for the unpracticed direction) than in the post-rotational nystagmus for the unpracticed direction (and in the rotational nystagmus for the direction of practiced), although the unavoidable occurrence of an indefinitely long rest period at the end of each session of repeated rotation tends to make the difference in the reduction of the two types of nystagmus less conspicuous than the difference usually obtained under the conditions described in 2. (This statement, like 2, is probably true only within limits: thus, if the duration of the rest intervals interpolated between the successive rotation intervals equals or exceeds the duration of the postrotational nystagmus, the differential effect just described cannot be expected to occur.)
- 4. The particular propositions posited in 1, 2, and 3 may be stated generally, as follows: The longer a given type of vestibular nystagmus is allowed to persist, uninterrupted by an opposing vestibular stimulus, the greater the likelihood that repeated elicitation will reduce the duration and magnitude of this response. (This proposition, previously stated in somewhat different terms by Holsopple (38), should, however, be regarded merely as a descriptive, not as an explanatory concept.)
- 5. Although vestibular nystagmus may be substantially reduced (about 60 per cent on the average) by means of repeated elicitation with vision excluded, this response cannot, however, be abolished (except, perhaps, at intensities of stimulation considerably weaker or stronger than employed in the present investigation).
 - 6. When the type of subject used in this investigation is rotated

with vision permitted, there is a vigorous nystagmus during the entire rotation period but little or no post-rotational nystagmus; repeated bodily rotation either in the clockwise or in the counter-clockwise direction or alternately in both directions does not perceptibly modify this pattern of response.

- 7. Repeated bodily rotation under the conditions described in 6 likewise does not affect either the rotational or post-rotational vestibular nystagmus produced by bodily rotation in either direction with vision excluded.
- 8. When bodily rotation is accompanied by concurrent rotation of the visual environment, there is a slight (acceleration) nystagmus at the onset of rotation and a slight (retardation) nystagmus at the end of rotation, both of which responses gradually disappear with repeated elicitation.
- 9. Repeated bodily rotation under the conditions described in 8, either in the clockwise or in the counter-clockwise direction or alternately in both directions, produces a slight (about 20 per cent on the average) and equal reduction in the vestibular nystagmus elicited during and after rotation in either direction with vision excluded.
- 10. Rotation of a visual environment around a stationary subject produces a vigorous nystagmus which lasts as long as the rotation of the environment is continued (or until the subject is fatigued) and which tends to persist for a brief time after the environment has been brought to rest; this persistence of the visually elicited nystagmus after the environment has been stopped gradually disappears with repetition.
- 11. Repeated elicitation of visual nystagmus under the conditions described in 10, with the successive rotation and rest intervals of equal duration, produces a decided reduction (about 50 per cent on the average) in the post-rotational vestibular nystagmus elicited by bodily rotation in the same direction as the repeated rotation of the environment but does not perceptibly modify the post-rotational vestibular nystagmus elicited by bodily rotation in the opposite direction.
- 12. Repeated bodily rotation in a given direction with vision permitted and head held in a fixed position with reference to the

body produces a significant reduction (about 45 per cent on the average) in the post-rotational vestibular nystagmus elicited by bodily rotation in the practiced direction but does not modify the post-rotational vestibular nystagmus elicited by rotation in the opposite direction.

- 13. Repeated bodily rotation in a given direction, with vision excluded and head held in a fixed position with reference to the body produces a significant (about 35 per cent on the average) and equal reduction in both the clockwise and counter-clockwise post-rotational vestibular nystagmus.
- 14. Repeated bodily rotation under the conditions described in 13 thus produces less reduction in both types of post-rotational vestibular nystagmus than does similar rotation with the head free (cf. 5).

The supposition that the reduction of vestibular nystagmus by means of repeated elicitation may be dependent upon injury to or structural modification of the vestibular receptors has been disproved by a variety of experiments which have been reviewed elsewhere (22), (59). The reduction process, whatever its specific nature may be, must, in all probability, occur somewhere within the central nervous system. This conclusion is consistent with the theory that the persistence of vestibular nystagmus after the cessation of actual physical stimulation is mediated by the action of a mechanism located within the central nervous system. On the other hand, this conclusion, as well as the experimental facts cited in the immediately preceding pages, is opposed to the notion that the reduction of vestibular nystagmus by means of repeated elicitation is dependent upon "fatigue" or upon "sensory adaptation" of the type characteristic of vision, taste, smell, and certain other sensory mechanisms.

Since vestibular nystagmus is a useless, mal-adaptive response under the experimental conditions in which it is most readily habituated, it has been suggested that the habituation may be dependent upon a learning process, fundamentally similar to the process involved in the elimination of other useless or harmful responses (Abels (1), Dodge (14)).

Since the conditions under which vestibular nystagmus is most

readily habituated are seldom or never encountered by most living organisms in their ordinary existence, it has been suggested that the habituation of this response may be dependent upon a breakdown or dissociation of normal, integrated functioning and may therefore represent a pathological rather than an adaptive type of process (Abels (1)).

So far as can be seen at the present time, none of the findings of this or any other investigation previously reported provides definitive, or even strongly presumptive, evidence in favor of either of the hypotheses just stated; but the experimental facts now available do seem to suggest that one or the other of these hypotheses is probably the correct explanation of the modifiability of vestibular nystagmus by means of repeated elicitation.

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#6

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MECHANISMS OF HANDEDNESS IN THE RAT

BY

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MECHANISMS OF HANDEDNESS IN THE RAT¹

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INTRODUCTION

In a preliminary report (16) I described a food situation in which rats were tested for right and left handedness. Food was placed in a canary feeding dish which was outside the cage. A part of the dish projected through the wire mesh of the cage and the rats had to reach into this and scoop up their food. This situation differentiates rats into right handers, left handers, and ambidextrous animals.

Certain questions immediately arise concerning these phenomena. What is the relative incidence of right and left handedness in large numbers of animals? Is the trait a relatively permanent one, i.e., will the animals be consistent in the use of their hands over relatively long time intervals? Can other situations be devised in which rats will exhibit the phenomenon of handedness or show a definite preference for one side of the body? If so, will animals be consistent from one situation to another, i.e., will animals that are right handed in the food situation also show a preference for the right side in these other situations? Will rats which are ambidextrous in the food situation eventually show a greater preference for one hand, or is ambidexterity also a relatively consistent trait? If practice alone cannot account for handedness, what other factors might operate to cause it?

¹ This research was begun in Professor Lashley's laboratory at the University of Chicago and was continued in the Animal Research Laboratory of the University of Denver. I am indebted to Professor R. G. Gustavson of the University of Denver for the opportunity to carry on the work there, and to the National Research Council for a grant which has enabled me to continue it. But my greatest obligations remain with Professor Lashley, as will be obvious to the reader acquainted with this field of investigation.

What are the cerebral mechanisms involved in handedness? To what extent is the trait localized? If it is localized, does this critical area correspond to the cortical area producing arm movements upon electrical stimulation? Will wide spread destructions outside a given locus influence the trait? What will be the effect of bilateral lesions, circumsection, surface lesions, homolateral lesions, etc. upon the trait? Is reëducation possible after the destruction of a critical area? What bearing will the results of investigations of cerebral mechanisms have upon current neurological theories? The experiments described below were designed to answer these questions.

CONSISTENCY IN THE FOOD SITUATION

In determining handedness in the food situation two different procedures were followed. In the case of animals which were operated upon and in the case of those observed over a long time period, the procedure was identical with that described in the preliminary report, the number of times the animal reached with either hand was recorded up to fifty reaching responses for each day's observation. In some of the breeding work and in all of the remaining work a count was not taken, but the animals were merely allowed to feed for five minutes or longer on several different days, and consistencies or inconsistencies were noted. The latter method was invoked as a time saving device. The two methods probably give essentially the same results as far as classifying the animals is concerned.

The records of 60 cases in which the reaches were counted are given in Appendix A. There are 30 left handers, 23 right handers, and 7 ambidextrous cases. However, these data throw no light on the relative incidence of right and left handedness, since the animals were not selected at random. Twelve of the 60 cases were observed over a period longer than seven months. Nine of these, Nos. 18, 19, 20, 28, 39, 40, 41, 56, and 57, were left handed for slightly longer than seven months. Two were right handed, one for more than seven months, No. 59, and one for more than a year, No. 58. The remaining animal, No. 60, was ambidextrous for sixteen months. One of the left handers,

No. 28, was subjected to electrical stimulation of his right cortex and subsequent extirpation of part of the area where arm movements were elicited without influencing his consistency. The left hand continued to be used for two months after this operation.

The eleven cases which were definitely either right or left handed for periods more than seven months long all attest to the consistency of the response in this particular situation. If an animal once exhibits right or left handedness, we may reasonably expect it to continue to do so unless an accident intervenes. Rats are not fortuitously and capriciously right handed on one day and left handed on another. The ambidextrous case, No. 60, illustrates that animals need not become predisposed to the use of one hand through practice and thus eventually use it exclusively. One ambidextrous case, No. 51, although it was observed during a normal period (before brain operation) of only 56 days, indicates that in some cases ambidextrous animals may become predisposed to an exclusive use of one hand which might be due to practice. On the other hand, another ambidextrous animal, No. 15, which showed a greater preference for the right hand at the beginning of observation, was showing a greater preference for the left hand when the observations were interrupted by operation. This is contrary to what would be expected if practice were a predisposing factor for hand preference. Other ambidextrous cases which failed to be influenced by practice during periods of observation of more than 50 days are Nos. 16, 52, 53, and 54. While it is true that animal No. 60 was observed only 14 times during the sixteen months period, she was more ambidextrous later than during the early periods.

OTHER TESTS FOR HANDEDNESS AND THEIR CONSISTENCY WITH THE FOOD SITUATION

While the cases cited above indicate a consistency of response for the food situation, it does not follow that animals will be consistent in favoring the use of the same hand in different situations. It is well known that human beings often exhibit inconsistencies in different situations while being consistent in any one situation, as witness baseball players who throw right handed and bat left handed. I therefore attempted to devise other situations to test the handedness of animals.

The latch box as an index of handedness. The first of these is a latch box requiring the pressing down of a lever above the door in order to open it and secure food. Wire mesh prevents the animal from having access to any part but the handle of the lever. Levers of three lengths were used, the longest extending more than an inch beyond the wire mesh into the confinement compartment. Preliminary training was given with this lever until the rats would open the door readily with their hands. The handle of the middle sized lever extended flush with the wire mesh. The rats were transferred to this lever from their preliminary training on the longest lever. They generally resorted to their mouth and teeth in opening the door when this lever fastened it. The third lever was too short to be reached with their teeth, and required reaching through the wire mesh with a hand. This proved to be a much more difficult task than those called for by the longer levers.

No time records on any of the levers were kept, and only when the short lever was used was a record kept of the hand used to open it. The individual records of seven animals which developed sufficient proficiency to solve the problem with their hands are given in Appendix B. These rats, Nos. 1, 2, 3, 5, 14, 15, and 31, were also tested in the food situation. Their records in this situation will be found in Appendix A.

The animals were required to reach for the short lever six times per day for at least five separate days. Thus there are at least thirty instances of reaching recorded for each animal.

The latch box situation also differentiates rats into right and left handed animals. In no case was an inconsistent response given. Of the seven animals, five are right handed and two are left handed. Of the five right handers, two are also right handed in the food situation, Nos. 14 and 31, while three are left handers in the food situation, Nos. 1, 2, and 3. Of the two left handers, one is right handed in the food situation, No. 5, while one, No. 15, is more or less ambidextrous but happened to be using his left hand more than his right in the food situation when he first

performed in the latch box. Thus we may say that four of the seven cases are not consistent in the use of their hands in different situations. This would lead one to expect that there is no relation between the two situations in determining the use of the hands, but a much larger number of cases is needed before this conclusion would be valid. The inconsistency does indicate, however, that handedness in the rat is by no means a simple characteristic.

The water tank as an index of handedness. Position habits are common phenomena in animal work. Yoshioka (22) has correlated position habits to body structure and to handedness. I used McDougall's (12) water tank situation to set up position habits which might exhibit bilateral asymmetry. The animals were thrown into a tank of water which offered a choice of two pathways for escape. One of them could be reached by swimming to the left and the other by swimming to the right. Six animals were given six trials per day for seven days. The individual records are given in Appendix C.

One of the animals, No. 7, developed a definite position habit to the left and another, No. 16, developed a less marked position habit to the right. Four animals developed only slight position habits, three of them, Nos. 4, 8, and 9, to the right, and one, No. 6, to the left. In the food situation, rat No. 16 was ambidextrous and No. 6 was right handed. The others were left handed.

It was assumed that if one hand was favored in eating, it would be stronger than the other and cause the animal to steer in this direction while swimming. The results, however, indicate at best a negative correlation which would be difficult to explain. The water tank situation was discarded for further investigation because it failed to differentiate animals into definite right and left handers. It easily arouses emotional conditions which could complicate the bilateral asymmetry in which we are interested. When I anthropomorphized, I felt that the animals thoroughly disliked the water tank and wondered if they did not occasionally try the non-preferred path to see if that way led to a solution which would prevent ducking. Furthermore, as

will be seen later, brain destructions produced unequivocal effects upon animals tested in the food and latch box situations. No such results could be detected in animals tested in the water tank.

THE INCIDENCE OF HANDEDNESS

The incidence of right and left handedness has been reported by Tsai and Maurer (19) for 105 normal rats and 54 vitamin B depleted rats, and by Yoshioka (23) for 100 normal rats. tests were similar to mine in the food situation. Before their results were published, I also tested in the food situation 120 animals selected from a large colony at random. Since all three investigations used different criteria of classification, it is doubtful if the results can be compared. Tsai and Maurer counted the number of times the animals used either hand in 250 reaches. Those preferring one hand 75 per cent of the time or more, were classified as right or left handed. All others were called ambidextrous. Yoshioka observed the animals for two periods of two minutes each. He then classified the animals into exclusive and non-exclusive right and left handers and into ambidexters, although he does not state how he differentiated non-exclusive preferences from ambidextrous cases. I did not count the number of reaches taken by the animals in my investigation of incidence but observed them for consistency of use for two periods of five minutes each on successive days. Those animals which were inconsistent were observed for a third period of five minutes on a third day. My experience had indicated that animals do not always show a preference in their early attempts to get food but make indiscriminate thrusts with their hands. Such animals often later show decided preferences for one hand and, if they showed such a preference in two successive observations, they were not classified as ambidextrous.

My results are shown in table 1 which indicates a larger percentage of left than right handed animals. The results are at variance with those of the other investigators if we disregard the differences in criteria in classifying animals. Yoshioka reports 50 per cent right handed, 45 per cent left handed, and

5 per cent ambidextrous animals. Tsai and Maurer report for their normal animals: males, 59 per cent right handed, 26 per cent left handed, and 15 per cent ambidextrous; and females, 43 per cent right handed, 37 per cent left handed, and 20 per cent ambidextrous. Thus the other investigators both report a higher incidence of right than left handedness.

Other evidence, from the inheritance of handedness to be reported below, leads me to expect about equal numbers of right and left handed rats. In my opinion, the figures above merely show the wide variation of results which can occur in random samplings. Yoshioka's results probably approximate more nearly the true incidence in the general population of rats. He reports a slightly larger percentage of non-exclusive right handers

TABLE 1

	R		L		A		TOTAL	
	Num- ber	Per cent	Num- ber	Per	Num- ber	Per cent	Num- ber	Per cent
Males	20	33	31	50	10	17	61	100
Females	22	37	31	53	6	10	59	100
Total	42	35	62	52	16	13	120	100

Incidence of handedness in rats selected from a large colony at random.

than of non-exclusive left handers, and one would only have to classify some of these as ambidextrous to equalize right and left handedness.

Tsai and Maurer have reported an increase of left handedness in their vitamin B depleted rats. My high incidence of left handedness might therefore be due to an inferior diet, a suggestion good enough if the findings regarding the influence of vitamin B on handedness are confirmed. But in view of the wide differences in incidence found in the random samplings of these three investigations, the work on the influence of vitamin B in handedness depending, as it does, on an incidental count, would have to be repeated several times on a large number of cases to give credence to the data. The data of Tsai and Maurer on normal rats show a decidedly higher incidence of right hand-

edness among males than among females. Yoshioka's data indicate a slightly higher incidence of left handedness among males than among females and no sex differences in right handedness. My own data indicate insignificant increases in both right and left handedness among females at the expense of ambidexterity. Thus the data of Tsai and Maurer indicate sex differences as well as vitamin B differences. But these sex differences are not borne out in other investigations, and we can only regard differences due to diet skeptically until they are verified.

The incidence of handedness in rats has been discussed in some detail since the findings indicate how easily results may be at variance and how investigations of this sort seldom answer the problem they are designed to answer. When several cooperating investigators working in different laboratories and employing the same criteria report congruous results for large random samplings of animals, the incidence of right and left handedness in rats may be approximately known, and not until then.

FACTORS DETERMINING HANDEDNESS

Since the ambidextrous cases which fail to be affected by practice indicate that this factor, although it may be effective in individual cases, is not the only factor, or even the predisposing factor in determining handedness, a series of experiments was conducted to see if some other cause could be found that would account for the phenomenon. While the results of these investigations are entirely negative, in some instances they at least inform us of what *not* to believe regarding the causal conditions in handedness.

Inheritance. I have been unable to find any proof in the literature that handedness is inherited in the human. Many writers seem to assume its inheritance without advancing any direct evidence in support of their contention. Thus Newman (13) writes:

Genetic handedness is evidently transmitted in such a way that any given zygote will give rise, when no twinning occurs, to a righthanded or left-handed single individual. There seems, however, to be varying degrees of right- or left-handedness. The majority of individuals, apparently about eighty per cent. of single individuals, are definitely right-handed; about four per cent. definitely left-handed, and the remaining sixteen per cent. partially left-handed or ambidextrous. The incidence of right- and left-handedness is about what one would expect if right-handedness is a dominant Mendelian unit character and left-handedness recessive. The ambidextrous individuals and those showing lesser degrees of left-handedness may be heterozygous individuals in which the dominance of right-handedness is incomplete.

Travis (18), in his recent book, also subscribes to this simple doctrine, referring to Jordan's work with approval.

Jordan states further that left-handedness follows very closely the Mendelian law of inheritance. In general it appears in heredity as a Mendelian recessive character. When a left-handed individual marries a right-handed individual, the children from the marriage are all right-handed. When such 'hybrid' right-handed offspring intermarry, however, the children are right-handed and left-handed approximately in the proportion of three to one. When strictly right-handed individuals marry and strictly left-handed individuals marry, the children all tend to be right-handed and left-handed respectively.

However, Jordan (4), himself, is a great deal more cautious concerning the hereditary mechanism. After mentioning that his results *suggest* Mendelian ratios, he states:

The writer does not however delude himself—nor does he wish to leave the impression of attempting to mislead his readers in this matter—that left-handedness even appears (on the basis of the limited data presented) to follow Mendelian principles of inheritance. The sole step of prime importance he insists on at present is that the phenomenon of left-handedness is hereditary in some way.

More recently, Chamberlain (2) has reported a statistical study in which a much larger percentage of the children of left handed parents were left handed than of children in whom only one or neither parent was left handed, and concludes, "there can be no doubt that the trait is inherited, but surely not as a Mendelian recessive." We can agree with that part of the statement which I have italicized. To agree with the entire state-

ment, we would have to assume that the expression of handedness is not subject to social influences (e.g., that the children of a left handed parent could not be left handed as a result of "social" heredity, imitation, or the like) factors which Chamberlain made no pretense of studying. In fact unless statistical studies give results conforming to a definitely stated hypothesis, they can hardly be said to prove anything. The final appeal is to experiment which is almost beyond the possibility of realization in the human.

TABLE 2

TYPE OF PARENT			NUMBER OF			
ę	₫	R	A	L	LITTERS	
R	R	11	4	19	8	
L	L	32	5	28	10	
R	L	10	4	6	4	
L	R	3	0	2	2	
A	L	5	0	3	2	
A	R	4	2	6	2	
R	A	3	0	1	1	
A	A	3	2	0	1	
Total		71	17	65		
Per cent		46	11	43		

Types of offspring resulting from various crosses of right handed, left handed, and ambidextrous parents.

I have been able, however, to test the hypothesis of inheritance of handedness in rats. In the light of the apparent complexities of the trait as revealed in the inconsistencies seen in different situations and in ambidexterity, various combinations of crosses have been resorted to. Right handed animals were crossed with right handers, left handed animals with left handers, and other combinations were used.

Table 2 summarizes the results of this breeding. It will be seen that neither right nor left handedness bred true and, therefore, that neither is recessive to the other. Eight litters from right handed parents included 11 right handed, 19 left handed, and 4 ambidextrous animals. Ten litters from left handed

parents included 32 right handed, 28 left handed, and 5 ambidextrous animals. Since these results would indicate that if handedness did have an inherited basis it would be necessary to inbreed both left and right handedness to get pure stock, nothing could be interpreted from the mixed crossings of right and left handed animals. Accordingly, these crossings were discontinued and inbreeding of right and left handedness begun. Thus far the inbreeding has been carried to the seventh generation without getting any noticeable increase in the purity of the lines. The only justifiable conclusion which can be made at present is that if handedness is inherited at all in the rat, it must be in terms of multiple rather than simple Mendelian factors.

As mentioned before, the breeding results may be used to shed light on the incidence of handedness. While it could be argued that there was selection rather than random sampling, yet many combinations were resorted to, and it must be remembered that the breeding results were negative. It is, therefore, difficult to see how selection operated, if at all, to affect the results. Of 153 offspring from the breeding experiment, 46 per cent are right handed, 43 per cent are left handed, and 11 per cent are ambidextrous. On the basis of these results, I should not be surprised if it were eventually concluded, from large numbers of cases, that right and left handedness are equally distributed in the rat population at large.

Influence of circulation. It has been suggested that handedness may be due to the asymmetrical arrangement of the carotid arteries which supply blood to the brain. In another report (17), I have published the results of an experiment designed to test this hypothesis and have concluded "that dominance of one hemisphere of the brain of the rat, as revealed in food reaching, is not due to unequal blood supplies coming from the two carotid arteries."

Position of the foetus. For a better understanding of behavior, more and more emphasis is being placed on its development and, in that regard, upon its foetal development. An excellent example of this point of view is to be found in Kuo (5) who writes:

The development of behavior is an absolutely gradual and continuous process. In this continuous stream of behavioral development we cannot pick up at a certain period one bit of response and assign to it the name of instinct and take another bit and call it a habit. The real nature of behavior cannot be understood unless its underlying physiology and the entire developmental history are known. Behavior does not make its appearance as a sudden manifestation, or outburst of maturation of instincts, nor is it acquired through trial and error learning; it is a result of gradual and continuous growth, and to understand it, we must study behavior from its earliest beginning.

This concept of gradual and continuous growth implies a multitude of factors operating upon behavior to make it plastic and variable rather than fixed and stereotyped and, as such, is useful in accounting for the many possibilities of posture (among other types of behavior) which Kuo is attempting to account for. But the fact remains that handedness is relatively fixed rather than variable for most rats in a normal environment. If there were manifold factors in embryonic development operating to produce handedness, should we not expect variable and plastic behavior as a result? That is, should not most animals be ambidextrous? However, the possibility remains that some constant factor in foetal development operates to produce the phenomenon of handedness. With this in mind, the following experiment was performed.

Right hysterectomies were performed in three females and left hysterectomies in three others. They were then bred and the young consequently carried in one horn of the uterus. One of the females had five litters totaling 22 animals. The others had one litter each. The mothers were examined after their young had been weaned and, in each case, one horn had been almost completely removed.

When the young reached adulthood they were tested for handedness in the food situation on six or more occasions. The results are shown in table 3. Thus, of the young carried in the left horn, 10 were right handed, 5 were left handed, and 2 were more or less ambidextrous. Of the young carried in the right horn, 14 were right handed, 15 left handed, and 3 more or less

ambidextrous. Twenty-two of these were from one mother, and of these, 11 were right handed, 9 left handed, and 2 more or less ambidextrous. It thus appears to make no difference in which horn of the uterus the young are carried.

In order to determine if some constant factor in the position of the foetus could be detected, an examination of several pregnant females was next undertaken. Examinations were made

TABLE 3

		OFFSPRING	
	R	A	L
Right hysterectomies:			
Female A	5	1	1
Female B	3	0	3
Female C	2	1	1
Total	10	2	5
Left hysterectomies:			
Female D	1	0	4
Female E	2	1	2
Female F:			
Litter No. 1	1	1	4
Litter No. 2	2	0	0
Litter No. 3	2	0	1
Litter No. 4	3 3	0	1
Litter No. 5	3	1	3
Total, Female F	11	2	9
Total	14	3	15

Types of offspring resulting from removing one horn of the uterus of the mother so that the young were all carried in one horn only.

of foetuses which were 13, 15, 18, 20, and 21 days old. The placenta was always found on the wall of the uterus where the blood vessels entered. The long axis of the young was always parallel to the long axis of the uterus. The foetus was headed toward the ovary in 26 out of 53 cases examined and in the reverse direction in the remaining 27 cases. While this simple fact might appear to be significant in accounting for left or right handedness, it presented no exceptions which could account

for ambidexterity. If the long axis of about 10 per cent of the foetuses had been arranged so as not to be parallel to the long axis of the uterus, this aspect of foetal position might then have had significance for handedness. The ventro-dorsal axis of the foetus exhibited a chance position with reference to the placenta. Furthermore the uterus itself wound a tortuous course from its bifurcation to the ovary in those animals with foetuses older than 15 days. The left or right side of the young could have any position with reference to gravity and, if this were a determining factor in handedness, we should expect many more ambidextrous cases than we find. Although the results of the experiment are entirely negative, the examination added nothing which might have suggested further experimentation aiming to control foetal position.

Eye dominance. Parsons (14) has pointed out a striking relationship between the hand and the eye in the human. He tested more than 800 school children with the manuscope and found that, although a very small percentage of right-eyed children were left handed, a very large percentage of left-eyed children were right handed. The great discrepancy among the left handers he ascribes to social pressure and education.

From this relationship he appears to deduce a causation in which the preferred hand is dependent upon the dominant eye, although I see no reason why the reverse should not be true, or better still, perhaps, that both are dependent on other common factors. However, Parsons states:

The manuscope determines native handedness by going to the cause. It is thus an indicator, not only of handedness, but also of eyedness, . . . Its sole function is to determine which visual line is used for sighting; and in determining this it helps to determine handedness.

According to present theory, handedness is caused by eyedness, the favored hand being the one on the same side of the body as the sighting eye. . . .

. . . Moreover, this fixedness of the sighting line settles most convincingly a point that otherwise might be somewhat difficult to clear up. We refer to the question as to which (of handedness and eyedness) is cause and which effect. Experiments with the manuscope supply the

answer and show us that while changes of handedness are always deliberately brought about, changes in eyedness are involuntary. In the one case the change is the result of design, in the other of nature. To put it differently, we can tamper with and to some extent control and change handedness, but we cannot permanently change the inherent cause of handedness.

In a footnote he adds:

"An interesting line of investigation here suggests itself: In infancy would the loss or serious disabling of the sighting eye and the consequent and forced transfer of the sighting faculty be followed by a transfer of handedness? With adults of fixed manual habit and perfected cerebral mechanism this would scarcely be possible; with children of very tender age it might be, provided the speech and other closely coördinated centers had not become too firmly established."

I should like to point out that, if Parsons' conclusion that handedness is caused by eyedness is correct, altering the eyedness

TABLE 4

RI	GHT EYE REMOVE	DD .	I	EFT EYE REMOVE	D
R	A	L	R	A	L
2	1	3	0	0	4

Types of handedness resulting in animals which had one eye removed before the eye lids had separated.

in infancy before manual habits had been established would necessarily cause transfers in handedness, not possibly cause them, as he infers. If any other result occurs, then eyedness is not the cause of handedness.

In order to test the possibility that hand preference depends on eye dominance, one eye of the rat was removed or enucleated when the animal was fourteen days old, i.e., before the eyelids had separated. Ten such animals were operated upon, 5 of which had the right eye removed and 3 the left eye. One animal had the right eye and 1 the left eye enucleated but not removed.

The animals were tested for handedness in the food situation when they reached adulthood. Tests were conducted on seven or more separate days. The results are summarized in table 4. Of 6 animals with the right eye non-functional, 2 were right handed, 3 left handed, and 1 ambidextrous. All 4 animals

with the left eye non-functional were left handed. After tests were completed, the animals were killed and the optic nerves examined. In every instance the nerve associated with the non-functioning eye was obviously smaller than the nerve leading from the functional eye. Enucleation of the eye appeared to have as great an atrophic effect upon the nerve as removal of the eye ball.

Only three cases fit with the hypothesis that eye dominance determines handedness, namely, the three left handed animals with the right eye removed. If we prefer to reverse the argument and link handedness up with the non-functional subordinate eye, these three cases become the exceptions. The ambidextrous case is an exception from either point of view. In the light of the negative results obtained in this experiment, it was fortunate that one of the ten cases happened to be ambidextrous. One would suspect ambidextrous animals to be more delicately balanced than those with strong preferences, and thus more susceptible to minor changes which might not be seen in the other cases. Of course, one could argue that rendering his dominant eye non-functional brought about the ambidexterity in this case. One would then have to explain why the other nine cases were not similarly affected.

If rendering an eye non-functional does not alter its dominance I do not see how the hypothesis can ever be put to an experimental test. The results reported, however, are not exceptions to the possibility that dominance of the eye and of the hand are both reflections of some other cause. We can only conclude on the basis of these results that the dominance of one eye is not a cause of preferential handedness in the rat.

CEREBRAL MECHANISMS IN HANDEDNESS

In the preliminary report (16) I showed that handedness in the rat depends on intact motor and somaesthetic fields in the opposite cerebral hemisphere. I do not regard this as a causal condition of handedness, however, for it merely raises the question as to the cause of the cerebral dominance. The brain may be regarded as a necessary part of a mechanism which reveals handedness. Removing any part of the mechanism necessarily interferes with its functioning, as would be obviously true if the hand itself were removed.

Correlations of motor phenomena with nervous structures range from studies involving relatively simple motor phenomena, such as the spinal reflex or the simple movements resulting from electrical stimulation of the brain, to the more complex acts of learning. Under the latter head are to be included those studies of animals involving the learning of puzzle boxes, mazes, and similar apparatuses. The last review of this extensive literature to come to my attention is that of Lashley (8).

Handedness appears to fall somewhere between the simple and complex phenomena mentioned above. It is, evidently, more complex than a simple reflex. Destruction of the reflex center abolishes the reflex. On the other hand, destruction of a part of the cortex leads to a transfer in handedness but not to a restriction in the use of the hand. The hand previously preferred is no longer used by preference. But it may be used if necessary, as I shall later show. And often, the transfer or recovery of use is gradual rather than abrupt. Such gradual changes can only be interpreted in terms of preferential use. This preference would make handedness something more complex than, for example, the spinal reflexes.

On the other hand, the handedness revealed in the food situation seems less complex than an act of learning. As was pointed out before, ambidextrous cases are exceptions to the expectation that practice should lead to a fixation, while definitely right and left handed cases exhibit the behavior before practice has any apparent opportunity to operate.

The conclusion in the preliminary study is based on seven cases, four of which were right handed, two left handed, and one ambidextrous. After operation in the contralateral hemispheres five cases transferred to the use of the opposite hand, the ambidextrous case used one hand exclusively, and the remaining case was disturbed but did not transfer permanently. All cases involved extensive destructions, the least percentage

involving 9.4 per cent of the area of one hemisphere, and the greatest 28.2 per cent. Four of the seven cases had subcortical structures, such as the caudate nucleus and the hippocampus, disturbed by the operation, and, of the remaining three, one was disturbed but did not transfer and one was ambidextrous in the beginning, so that only one was a clear cut transfer case due to cortical injuries.

The experiments to be reported below were designed to check and extend the results obtained in the preliminary report. Fifty-five animals were tested in the food situation, seven in the latch box, and six in the water tank. They were then subjected to cerebral operation.

General methods. In testing animals in the food situation, observations were generally made uniformly. The animals were observed and the reaches counted individually on at least seven separate days before the operation. The only exceptions are Nos. 12 and 17 who were observed on only six occasions. With eight exceptions they were observed again two weeks after the operation for seven consecutive days (omitting Sundays and holidays) and then, if their performances were stable, once per week for about two months after the operation. If their performances became irregular at any time, they were again observed on consecutive days. In five of the eight exceptions, the procedure was the same except that observations were not begun until three weeks after the operation (Nos. 1, 2, 4, 6, and 12). The other three exceptions were tested before a two week period had elapsed after the operation, one the day after the operation, No. 11, one three days afterward, No. 17, and one seven days afterward, No. 31.

After the second observations had been completed, the animals were killed and the brains dissected out. A rough sketch of the lesions was then made. Thereupon the brains were fixed, sectioned, and stained, and the lesions reconstructed according to the method described by Lashley (6). The lesions were mapped for individual cases and comparisons of their locus and extent made in the light of the behavior results obtained from the operations.

The maps of the brains showing the lesions in black are given in plates 1 to 4. The percentage of destruction is given on the map of each brain above the hemisphere that was injured. The figure on the left hand border refers to the number of the rat. In a few instances it was difficult to determine the extent of the lesions. Where there was doubt about the functionality of an area, the map is stippled and two percentages computed, that for the known destruction, and that for the entire possible destruction. All percentages were computed with 100 per cent equal to the total area of one hemisphere. Previous workers have used the total area of the brain as equal to 100 per cent. Since these cases involve bilateral asymmetry, it seems desirable to make this slight change.

Various types of operation were performed, and it seems best for the sake of clearness to deal with the cases in groupings based on these types. However, not all operations were successful from the standpoint from which they were undertaken. Such cases might better illustrate another effect, and where this is the case specific mention is made of it.

Homolateral destructions. Six cases had operations performed on the homolateral hemisphere. Two of them, Nos. 5 and 6, were right handed. The right occipital region was destroyed in No. 5 and the right frontal area in No. 6. Four of them, Nos. 1, 2, 3, and 4, were left handed. The left frontal area was destroyed in these cases, and the somaesthetic and some occipital regions as well in No. 4. In none of these cases was any effect noticed on their handedness, unless we include the slight occasional ambidexterity of No. 3, which failed to appear at any time after the operation.

No effects were expected. These cases were also trained in the water tank or latch box situation where their performance was inconsistent with that given in the food situation. The operation was aimed to disturb their performance in one of the first two situations, and was, therefore, incidental as far as the food situation was concerned. These data are presented to show that we do not have to deal with "the cortex as a whole" as far as handedness is concerned. This asymmetrical characteristic has an asymmetrical reflection or foundation in the cerebral cortex.

Contralateral frontal and somaesthetic destructions. Ten additional cases similar to those reported in the preliminary study were made in this study. The object was to delimit the critical area causing transfers in the use of the hand by comparing those cases which transferred as a result of the operation to those which did not. Six of the cases (Nos. 7, 8, 9, 10, 11, 12) were left handed and were operated in the right hemisphere. cases which were right handed, Nos. 13 and 14, were operated in the left hemisphere. The two remaining cases were ambidextrous. One, No. 15, was operated in the left hemisphere and the other, No. 16, was operated in the right hemisphere. Six of the cases, Nos. 7, 10, 11, 12, 13, and 15, were affected by the operation and four, Nos. 8, 9, 14, and 16, were not. In two of the six affected cases the transfer was complete from the time of the first observation and was permanent for 66 and 94 days after the operation (Nos. 11 and 12). One case, No. 13, neither transferred nor reached a single time with the originally used hand. He used his tongue to get at the food, and when the food level fell too low to be eaten this way the animal stopped eating. He was left hungry in the observation cage overnight on five successive nights from December 9 to 12. There was always some food in the bottom of the dish the next day. I have occasionally had animals which did not eat readily. After leaving them in the food situation overnight I have invariably found the dish clean the next day. Cases with bilateral destructions can be reëducated to reach. No. 13 is an exception which I have never duplicated.

Two of the transfer cases continued to use the originally preferred hand during the early observations after the operation. The transfer effects were not manifested in No. 15, an ambidextrous rat, until twenty-eight days after the operation. He then used his right hand exclusively until ninty-two days after the operation, when observations ceased. Transfer was first manifested in No. 7 thirty-five days after the operation and was complete fifty-seven days after the operation. It was permanent

until ninty-two days afterward when observations were no longer made. We can assume that the cortical degeneration which led to a transfer in these two cases did not occur until some time after the operation. One case, No. 10, never transferred completely, although seldom using the originally preferred hand.

By comparing the common areas of destruction in the cases which were affected to those which were not (see plates 1 and 2). we are able to delimit a region between levels 3 and 9 on the dorsal portion of the cortex which appears necessary for the continued use of the hand. It may be significant that the cases which delayed their transfer and the cases which never did transfer had destructions which did not extend as far forward as level 5. The cases which did not transfer do not involve these levels, or, if they do, as in the case of No. 14, the destruction is too lateral to involve the critical area. The destruction in one of the cases which did not transfer, No. 8, is posterior to level 9. However, gliosis extended forward to level 7. The tissue between levels 7 and 9 may or may not have been functional. is not possible to know whether the intact tissue between levels 5 and 7 was sufficient to carry out the function or if the doubtful area really continued to function.

A comparison between the two ambidextrous cases brings out an important fact. No. 15 was disturbed by a 7 per cent destruction involving the critical area while No. 16 was not affected by an 18 per cent destruction not involving this area. Apparently, within the limits set by these two cases, the locus of destruction is more important than mass. This does not prove, however, that destructions larger than 18 per cent outside the critical area might not produce transfers.

Contralateral occipital and temporal destructions. Seven cases involved extensive destructions in the occipital and temporal regions. The occipital region was explored better than the temporal, the lower part of which is difficult to get at. Four of these cases were left handed (Nos. 17, 18, 19, and 20) and three were right handed (Nos. 21, 22, and 23). The destructions ranged from 28 per cent to 54 per cent of one hemisphere. Not one of these cases transferred as a result of the operation. Pro-

tocol observations indicate that two and possibly three of the cases (Nos. 19, 22, and possibly 23) may have shown some slight incoördinations. These observations read:

No. 19 2/6/31 "Noticed some difficulty in reaching; a kind of scraping" (rather than the usual grasping).

2/11/31 "Scraping with left hand not so noticeable; grasping successful."

No. 22 4/22/31 "Immediate left hand feeding, but animal overreached and did not reach down so well."

No. 23 4/15/31 "Reaches may possibly be less steady than before. Still noticeable on 6/1/31."

These incoördinations may possibly have been diaschisis effects. Since the animals showed no obvious defects we have no way of interpreting these symptoms. However, they are of minor importance compared to the transfer effects produced by frontal injuries. Occipital and temporal injuries involving more than 50 per cent of one hemisphere are unable to produce transfer effects where much smaller frontal injuries do cause transfers. Save for the 18 per cent destruction in No. 16 we cannot say that gross lesions outside the critical area would not affect the more delicately balanced ambidextrous cases. Work of this sort is being done at present but is incomplete. The results so far obtained lead one to question whether a "general" dominance of one hemisphere over the other is anything more than a myth.

Destructions within the Electrically Stimulable Area. The results thus far obtained led to a further delimiting of the area controlling handedness. In nine cases the electrically stimulable area of the cortex was explored. Five cases were left handed (Nos. 24, 25, 26, 27, and 28) and four were right handed (Nos. 29, 30, 31, and 32). In two cases, Nos. 29 and 30, unipolar stimulation was resorted to. In two other cases, Nos. 24 and 32, unipolar stimulation failed to elicit movements where bipolar stimulation succeeded. Bipolar stimulation was used exclusively in the remaining five cases. The movements produced in the rat are not highly differentiating at their best. With unipolar stimulation right arm, leg, and head turning (neck) movements were elicited in No. 29; right arm and head turning in No. 30.

With bipolar stimulation, arm movements only were elicited in Nos. 24, 26, and 31. Arm movements appear to be as easy as any to produce, and when they occurred in Nos. 25 and 27, no other movements were attempted. In No. 32, after unipolar stimulation was unsuccessful, bipolar stimulation gave arm, leg, and vibrissae movements. The leg movement could not be produced a second time, but the arm area extended back to it so that stimulation of the "leg area" now gave arm movements. Leyton and Sherrington (9) described similar deviations in response to electrical stimulation in primates. None of their deviations involved muscle groups as far removed as the front and hind leg, however. But the distance between cortical loci for fore and rear leg movements in the rat is no greater than that involved in many of the deviating responses which they reported. This deviation in the rat is not very surprising, therefore, in the light of their findings. The method of electrical stimulation was used in later cases to identify the area desired. In all these cases but one the arm movement elicited simulated a salute movement. This exception gave a fan-like spreading movement of the fingers, but no salute movement.

In all but two cases, Nos. 30 and 31, the operation was performed by knife. In these two a cautery was used. In one case, No. 29, there was a spreading of the destruction to involve 15 per cent of the cortex. This case transferred immediately and completely as a result. The other cases had destructions ranging from 0.6 to 3.9 per cent. Only one case, No. 32, transferred immediately and completely. His destruction amounted to 3.1 per cent involving levels 3 to 9 on the dorsal convexity. No. 32 represents the case with the smallest destruction to produce a complete transfer of the 55 cases reported in this study. One case. No. 30, showed a delayed and never entirely complete transfer but was doubtlessly definitely disturbed by the operation. The destruction amounted to 3.1 per cent and involved levels 5 to 9. One case, No. 31, may have been slightly disturbed soon after the operation, since he took three left handed reaches in each of the first three re-observation periods. These reaches were always the first three of the fifty reaches he took. (It will be noted that only four reaches were taken in the first reobservation period which was made one week after the operation.) This early effect (?) was soon overcome and no disturbance was noted thereafter. The destruction, amounting to 1.6 per cent, involved levels 5 to 8 and is more lateral than the two cases obviously disturbed.

In the remaining cases, no disturbances occurred. In two instances the destruction may have been too slight. One case, No. 25, showed a 0.6 per cent destruction from levels 5 to 6, and the other, No. 27, a 1.6 per cent destruction from levels 4 to 8. We can assume that enough tissue was intact to carry out the function of handedness in these cases. The failure of the other cases to transfer is more difficult to explain since their destructions are comparable to those which did transfer. No. 26 had a 3.1 per cent destruction involving levels 5 to 13. It may not be wide enough to impair the critical area. The lesion, amounting to 2.7 per cent in levels 5 to 10, in No. 28 may be too laterad. The 3.9 per cent lesion in levels 6.5 to 14 may be too caudad in No. 24.

We seem to have reached a critical point between the relative influences of mass and locus. Evidently the locus of destruction is of primary importance, since large destructions outside it do not produce transfers. But equally apparently, there is a mass greater than 3 per cent surrounding this locus which must be destroyed in order to produce transfers. If we assume that the destruction in No. 32 localizes and at the same time defines the extent of the handedness area, we can understand why some of the cases involving destruction in parts of the area were unaffected or only temporarily disturbed. The method of electrical stimulation only roughly defines the area which must be destroyed in order to cause transfers. The variability of response investigated by Leyton and Sherrington and noted for the rat in this study coupled with the fact that a definite mass of tissue must be extirpated to produce relatively permanent effects prevents this method from being more exact.

Circumsection. One type of operation failed to produce the desired effects but some of the cases furnished good instances of

small destructions which produce transfer. The object was to cut about three millimeters deep around the critical area without removing any tissue, attempting thus to isolate the enclosed area from the remainder of the cortex. Six cases involved this type of operation, three of which were left handed (Nos. 33, 34, and 35) and three of which were right handed (Nos. 36, 37, and 38). In three of the cases, Nos. 36, 37, and 38, the critical area was determined by bipolar electrical stimulation and two trephine openings were made into the skull to have a larger area within which to work. There was a spread of destruction in all three cases. Whether this was due to the effects of the stimulation, to cutting off the circulation, to the missing protective skull, or to some unknown factor cannot be determined. Whatever its cause, these cases merely corroborate previous findings. destructions in two cases. Nos. 36 and 38, involved the critical area. They both transferred. The third case, No. 37, was affected but recovered the use of his hand. The critical area did not seem much invaded, although adjacent to it, laterally, was shrunken cortical tissue whose functionality was difficult to determine. This area is stippled on the chart.

In the other three cases (Nos. 33, 34, and 35) the circular lesion was cut around the trephine opening without attempting to localize the area by electrical stimulation. In No. 34, the area isolated was stimulated immediately after the operation and arm movements induced. This case was disturbed by the operation but recovered after three days of re-observation. The recovery was complete thereafter with the exception of one day when she used the non-preferred hand three times. Of the remaining two cases, one transferred (No. 33), although the transfer was not complete until after four periods of re-observation. The other case, No. 35, was disturbed but this disturbance was not shown until after eight re-observations had been made.

Histological examinations of the brains of these cases showed no spreading of the area of destruction. However, the area supposedly isolated by the operation had degenerated in two cases, Nos. 34 and 35. In the third case, No. 33, there was doubt as to the functionality of a small enclosed area and the computed area of destruction, 5.3 per cent, includes this doubtful region. Thus, although this type of operation failed, these cases furnish more evidence regarding the localization of the handedness area.

Bilateral lesions. Since injuries to a definite area in the contralateral hemisphere lead to transfer in the use of the hand. what would be the effect of lesions in the critical area of both hemispheres? Would the animal no longer be able to reach for food? Would he be ambidextrous? Or might he reëducate one hand by practice and continue to show a preference? If the last were true, would it always be the hand preferred before the operation? To answer these questions seven animals were operated in both critical areas simultaneously. Three of these cases were left handed (Nos. 39, 40, and 41) and the other four right handed (Nos. 42, 43, 44, and 45). One case, No. 40, was unaffected by the operation. The destruction in the right hemisphere missed the critical area completely and, since she was left handed before the operation, she remained so afterward. Another left handed case, No. 39, was not seriously affected by the operation although the lesion seemed to involve a good part of the critical area. I have no explanation for her rapid recovery.

The remaining five cases were seriously impaired. One case, No. 42, transferred but the use of the transferred hand was decidedly unskillful at the start. The other four cases continued to use the originally preferred hand but just as unskillfully as the transfer case. As practice continued, all five cases showed improvement. They are genuine reëducation cases. In order to give an adequate picture of the disturbances produced, I shall include the notes made at the time of the re-observation of these cases:

No. 41 2/10/31 "Tongue feeding with occasional scraping of food into a pile so that tongue could reach it. Used left hand for these scrapes and did it awkwardly. Sometimes managed to grasp food with left hand but as often missed dish altogether when reaching. I counted total reaches, not successes, here to save time. Seldom used right hand for reaching. When I pushed food into emptied dish, rat returned to tongue feeding."

No. 41 2/11/31 "Improved greatly in successful reaching."

No. 42 4/22/31 "Tongue feeding. Bit on dish like a beginner. Left hungry overnight."

4/23/31 "Started with tongue feeding. When food got low in dish, rat swung over to his right, tipped head to right, with mouth to left. Right hand stuck through wire mesh attempting to reach food. Left hand on back of dish. Thus, left hand was in a better position to reach for and get food successfully than right. Only five of right handed reaches went to mouth with food while forty-five lefts did, yet right was attempted more often than left. When I filled dish, rat returned to tongue feeding."

4/24/31 "Right hand still awkward. Left hand improving."

4/25/31 "Right hand still attempting; left succeeding."

4/27/31 "Right hand not attempting so often. Left hand improving."

6/8/31 "Left hand used fairly well, but not as skillfully as a normal animal. Right hand still attempting, but not continuously.

Rat did not tip head so much. After 40 reaches his stance was much like a normal left hander."

No. 43 4/15/31 "No reaching. Tongue feeding altogether. Left in feeding cage overnight."

4/17/31 "Six left handed attempts unsuccessful. Right handed reaches did not seem so very unskillful although they may have improved from practice at night, when animal was not observed. Tongue feeding on full dish."

4/18/31 "Still somewhat awkward. Grew better after 10 reaches. It appears difficult for this animal to get started."

6/1/31 "Tongue feeding on full dish. Right hand not completely recovered but much improved over early observations. This animal is better than No. 45 but not as good as No. 44."

No. 44 4/15/31 "Tongue feeding at first, then clumsy reaching with right hand."

4/16/31 "Would not eat. Left hungry overnight."

4/17/31 "Tongue feeding on full dish but right hand improving."

4/18/31 "Right hand shows improvement. Used from the beginning."

4/22/31 "No unsuccessful right handed reaches but still uses tongue on full dish."

6/1/31 "Tongue feeding on full dish but right hand almost completely recovered in skill."

No. 45 4/15/31 "Tongue feeding at first. Later awkward reaching movements.

Left hand surpassed right at first, then right predominated."

4/17/31 "After tongue feeding, alternate unsuccessful right and left reaches, then fairly good right handed reaches. Returned to tongue feeding when dish was filled."

4/18/31 "Still awkward, but not as many left handed attempts. Improved after about 10 reaches. The early reaches seem harder to perform."

No. 45 4/22/31 "This animal is clumsier than No. 43 although he shows more readiness and starts reaching sooner. He makes more unsuccessful left handed reaches than No. 43."

6/1/31 "Tongue feeding on full dish. Not a complete recovery of right hand but much better than at beginning of reobservations."

It will be noted that no permanent ambidexterity resulted in any of these cases. A preference for one hand is shown as practice continues. Nor is the relative size of the destructions in the two hemispheres correlated to the hand used, within the limits of the experiment. Thus, of the four cases which did not transfer, two used the hand involving the hemisphere of greater destruction (Nos. 41 and 45), while the remaining two (Nos. 43 and 44) had greater destructions on the hemisphere which was not involved with the hand used. While it may be argued that the hand previously used was prepotent over the small differences in the relative size of the bilateral lesions in Nos. 41 and 45, the argument is weakened when the transfer case, No. 42, is considered. This case used the left hand after the operation although the greater destruction was on the right hemisphere. When the notes made at the time of the re-observations and reproduced above are taken into consideration, it appears to be merely a matter of chance as to which hand will be used immediately after the operation. Thereafter, practice seems to be the controlling factor.

Reëducation. The animals with bilateral distruction indicate that reëducation is possible after cerebral destruction. In transfer cases where only one hemisphere is insulted, reëducation should be possible if the hand transferred to is prevented from being used. This was done in four cases (Nos. 10, 11, 12, and 32) by binding with adhesive tape the hand used after the operation. The bandage was left on for three days, on the last two of which the animals were forced to take 50 reaches on each day with the hand affected by the operation. After the second period, the bandages were removed. All four animals showed decided weakness of the bound arm. They were observed on succeeding days and three of the animals returned immediately to the use of the hand transferred to. One case, however, (No.

10) which had not completely transferred, was now quite ambidextrous and remained that way for 45 days. During this time the bound arm seemed to have fully recovered its strength so that the continued use of the left hand would appear to have resulted from reëducation. As to the limits of such reëducation, however, no systematic work has as yet been done and we can only conclude what is already generally known of it, that it is a possibility.

Surface lesions. In the preliminary investigation only three of the seven cases reported were free from subcortical injuries. One of these was affected by the operation but recovered the use of his hand. Another was ambidextrous to begin with and eventually used the hand not affected by the operation exclusively. Thus only one case with no subcortical destruction showed a definite preference for one hand before the operation and for the other afterward. In this study, therefore, an attempt was made to strip off about 1 mm. of cortex by knife and thus leave the subcortical structures intact.

Nine cases involve this type of operation. Three of them were right handed (Nos. 49, 50, and 51), three left handed (Nos. 46, 47, and 48), and three were more or less ambidextrous (Nos. 52, 53, and 54). In all but one of these cases, No. 48, the area was identified by electrical stimulation which induced arm movements.

Three cases were not affected by the operation (Nos. 50, 51, and 52). Histological examinations of the brains of these cases revealed no subcortical injuries, in fact, that the operation was performed too conservatively. For instance, in No. 52 only the dura mater was removed anterior to level 9 and but a small part of the cortex was injured posterior to this level. In No. 51 not all of the layers of the cortex were removed. The map of the lesion in this case is drawn to show a maximum destruction to any layer. Shrinkage of a part of the brain was revealed in No. 50 and is stippled on the map. The actual lesion, shown in black, was very shallow.

Of the affected cases, the operation did not always accomplish its purpose. In No. 49 the left lateral ventrical and left caudate nucleus were somewhat distended, although the latter was nowhere invaded. This case definitely transferred. The cortical injury involved 10 per cent of the frontal lobe. In No. 47 the dorsal aspect of the head of the caudate nucleus was very superficially invaded. Seven per cent of the frontal pole was injured. The case transferred completely.

In the remaining cases the subcortical structures were intact and normal appearing as compared with the symmetrical structures in the opposite hemisphere. No. 48 transferred completely as a result of a 7.4 per cent destruction in the frontal pole. No. 46 showed incomplete but unmistakable transfer as a result of a 4.7 per cent destruction in the frontal region. No. 54 was quite ambidextrous before the operation. He used the right hand exclusively as a result of a 5.1 per cent destruction in the right frontal region. Immediately posterior to the lesion about 2 per cent of the cortex was shrunken and is stippled on the map. No. 53 was ambidextrous before the operation. A lesion amounting to 4.3 per cent seemed to affect this case for two months after the operation. Thereupon he displayed signs of recovery and observations were continued intermittently for three more months. The recovery appears to be genuine.

All of these affected cases have the cellular layers of the cortex insulted in one part of the lesion or another. The evidence seems to indicate that lesions must involve a certain depth to produce transfers but our technique is not yet sufficiently refined for its exact determination. These cases clearly show, however, that injury to the cortex alone produces transfer in the use of the hand.

With the question of the influence of subcortical disturbances in mind, an examination of the remaining operational cases reported in this study was made. Sixteen of them revealed no subcortical injuries (Nos. 3, 24, 25, 26, 27, 28, 30, 31, 32, 33, 34, 35, 42, 43, 44, and 45). Nine of these cases were affected by operations in the frontal regions (Nos. 30, 32, 33, 34, 35, 42, 43, 44, and 45). Three of these (Nos. 32, 33, and 42) transferred completely. Twenty-nine cases involved subcortical disturbances. Transfers failed to occur in eighteen of these. Five involved homolateral operations, in four of which the head of the

caudate nucleus was invaded (Nos. 1, 2, 4, and 6). However, since most of this nucleus remained intact, these cases only indicate that small homolateral invasions of this body have no effect. In the remaining homolateral case, No. 3, the corpus callosum was interrupted from levels 13 to 21 and the anterior portion of the hippocampus somewhat invaded without effect. Gross contralateral hippocampal injuries had no effect on No. 20 nor on Nos. 19, 22, and 23, although these last three cases showed coördination disturbances already mentioned. Since the hippocampus was almost completely destroyed in No. 20 without this incoördination, it seems unlikely that it would be due to the hippocampal injuries in the other three cases. These disturbed cases also had injuries in their corpora striata (Nos. 22 and 23) or in the thalamus (No. 19) which could more readily account for the disturbances noted.

Of the various subcortical structures, it is the corpus striatum which, on the basis of present knowledge, we should most expect to be related to our behavior problem. Subcortical disturbances in the contralateral hemisphere of cases which did not transfer did not involve this structure. In order to have done so, frontal injuries would also have resulted, and the cases would probably have been disturbed by this distruction. This analysis, therefore, offers no proof that the corpus striatum is not involved in handedness. It merely shows the extent to which other subcortical injuries failed to produce an effect. Conclusions concerning the functioning of the corpus striatum in handedness will have to await further experimentation.

Control of operational technique. The reader may be curious as to why the maps of the lesions in a number of these cases reveal stippled areas where there was doubt as to whether the cortex was functional or not, when similar studies do not present so many doubtful cases. In most of this work a single trephining is sufficient to admit the thermocautery whereby the destructions are made. In a number of my cases, however, two trephine openings were made into the skull, and the intervening bone removed in order to have a larger working field for electrical stimulation. Shrinkage often resulted after this larger exposure.

We have one case, No. 55, in which one trephine opening was made and no cortical tissue destroyed. Since this was a right handed animal, the trephine opening was made into the left frontal region in the same approximate locus as the other contralateral frontal operations. After trephining, the brain was exposed for a time comparable to that in cases in which destructions were made. Thereupon, the wound was sewed.

This animal did not transfer, nor could any other behavior effects of the operation be noted. Histological examination of the brain revealed no shrinkage or other change in the appearance of the cortex. This case, therefore, throws no light upon the effect of cortical shrinkage on the functionality of the tissue. It does reveal, however, that the transfers produced do not result from the pressure exerted in trephining, the antiseptic used, etc., but rather from the actual destruction of cortical tissue which follows these steps in the operation. All of the negative cases, i.e., those which did not transfer after the operation, also support this conclusion.

Influence of lesions upon behavior in the water tank. Six animals which were tested for position habits in the water tank were subsequently operated upon and retested. Since their handedness was also observed in the food situation, this aspect has been discussed above. It will be recalled that two animals, Nos. 7 and 16, developed rather definite position habits while four animals developed only slight position habits (Nos. 4, 6, 8, and 9).

The operations had no effect upon the position habits so far as I could determine. No. 7 continued its definite position habit after the operation. However, it will be noted that this animal did not transfer in reaching until much later. Unfortunately, it was not tested in the water tank after the transfer occurred. No. 16 may have had a right position habit broken up by the operation. We could have more confidence in the results if a left position habit had resulted. Instead, the animal continued to prefer the right alley in a 4:3 ratio.

In three of the four remaining cases, Nos. 4, 6, and 9, the position habits became more pronounced after the operation,

in spite of the fact that the destructions involved the critical area in the first two cases. In the fourth case, No. 8, the position habit became more pronounced, as it should have, since the operation involved the same side as the animal showed a preference for. This case did not transfer in reaching, indicating that the critical area for this act remained functional.

In the light of the equivocal results on these six cases, the water tank situation was not investigated further. It might be that a more systematic and complete investigation of the structures involved in the habit would furnish cues that would make the results reported here more explicable than they appear at present. On the other hand, Loucks (10) also failed to find a correlation between a position habit and minor asymmetrical destructions of the motor cortex.

Influence of lesions on behavior in the latch box. As against the results obtained in the water tank, operations on animals which learned the latch box produced intelligible results. Operations were performed in the contralateral hemisphere in every instance. Before the operation all of these cases used one hand exclusively in opening the latch box. Every case was given at least thirty tests on five different days, and one animal was given fifty-four tests on nine separate days. Two cases transferred as a result of the operation. In one animal, No. 1, the transfer was immediate and complete. She never did use the hand affected by the operation to solve the problem. The other case, No. 2, transferred more gradually, using the affected hand two out of five times on the first day, two out of six times on the second, one out of six on the third, two out of six on the fourth, and one out of six times on the fifth day of retesting. On three succeeding days she used exclusively the hand transferred to 18 times. The injury in both of these cases involved the critical area found necessary in the food situation.

Transfers did not occur in the other five cases. No. 14 also failed to transfer in the food situation. There was a delayed transfer in the food situation in No. 15. Unfortunately, he was not tested in the latch box after this transfer in the food situation had taken place. There was no check on No. 3 as this animal

was right handed in the latch box and left handed in the food situation. Part of the critical area was invaded but enough of it may have been intact to carry out the function. An 18.7 per cent destruction in the somaesthetic and occipital regions had no effect on No. 5. This is a larger lesion than either of the two in the frontal area which produced transfers in Nos. 1 and 2. No. 31 had a very small destruction (1.6 per cent) in the electrostimulable area. One week after the operation some influence may have been effected in the food situation when none was seen in the latch box on the same day. This animal soon recovered as far as food reaching tests were concerned, so that this disturbance may not be significant. He never seemed affected in the latch box.

The unequivocal transfers produced in two cases make the latch box a further test for bilateral asymmetry. Since latch box behavior is evidently complex and involves learning, it may be used to investigate problems of nervous functioning in which behavior in the food situation, because of its simplicity, cannot be used. Tests of the degree of localization and of the influence of the homolateral hemisphere on the latch box habit are being conducted at present.

AN INTERPRETATION

Recent neurological literature has shown strong tendencies in opposition to the doctrine of localization of function. As a result of his researches on what may be termed higher mental processes, Lashley has been especially critical and has suggested alternative hypotheses. No doubt the doctrine of localization of function carried to an extreme, can lead to absurdities. Psychologists no longer expect, if they ever did in the past, to find a neurone for every idea. In fact, I dare say a majority of them have given up hope that teams of neurones (reflex arcs) will ever be isolated and shown to represent any kind of mental units. We are in need of a new mode of analysis, a new approach, in order to correlate function and structure successfully. Fruitful suggestions are to be found especially in the recent works of Lashley (6) and of Maier (11).

On the other hand I doubt if we are ready for the right-aboutface which some critics are demanding. That we should discard, ignore, or misinterpret the facts known at present concerning the localization of function in order that they may better fit a theory seems questionable. To show that localization is an ill-devised concept with reference to maze learning, reasoning, and the like, is one thing. To assume that it likewise breaks down when applied to much simpler phenomena, of which handedness appears to be an example, is quite another.

In support of localization, Lashley (7) himself writes:

In the field of neurophysiology no fact is more firmly established than the functional differentiation of various parts of the cerebral cortex. We are removed from Flourens by nearly seventy-five years of intensive anatomical research which has settled beyond question the histological diversity of the cortical fields and of their connections with subcortical nuclei. A wealth of physiological and clinical evidence accords with the anatomical findings and proves the association of at least the majority of the cortical field with special functions. No one today can seriously believe that the different parts of the cerebral cortex all have the same functions or can entertain for a moment the proposition of Hermann that because the mind is a unit the brain must also act as a unit.

Yet the problems of localization and of cerebral physiology are far from solved by the demonstration of the anatomical diversity of the cortical fields and of consistent symtoms following the destruction of each. From the practical view of diagnosis there are still problems of the fineness of localization, of the types of function which are localizable, of the significance of individual variations, and the so-called negative cases.

In a 1933 publication he stated the problem as follows:

The association of diverse cytoarchitectural areas with different functions is well established, but the fact has been emphasized until it obscures the really fundamental problems of cerebral physiology. The production of specific symptoms by restricted cortical lesions furnishes a valuable clue to the nature of cerebral organization but, considered alone, provides no adequate picture of the processes which determine integration. We cannot accept an interactionist theory which localizes

psychic entities in the cortical field and then appeals to psychological laws to explain adaptive behavior. The facts of cerebral localization leave unanswered the question of how the specialized areas carry out their functions and of how their functions are interrelated.

However, some of the recent critics, apparently in their desire to find support from others for their point of view, seem to me to read but half the story. Thus Perkins (15) states:

The extirpation studies of Lashley and others, demonstrate conclusively the fallacy of the localization of function theory. The studies just reviewed, although not specifically designed to demonstrate this fact in audition, show possibilities in this direction and bear out the facts which earlier investigators like Kalischer, Rothmann and Swift found in their attempt to locate the auditory function. The lack of specificity of function noted by these investigators harmonizes well with the views of mass action and equipotentiality outlined by Lashley. Moreover, Lashley found incidental evidence pertaining to the so-called auditory region. When this area was destroyed in the rat, there was no observed difference in the rate of learning or in the retention of the problem-situations, which Lashley used to test his animals. In fact, no specific area in the cortex was essential for the performance; rather, a certain mass of the entire cortex was required for the solving of the problems presented.

Perkins fails to point out that the habits for which Lashley found the auditory area unimportant did not involve auditory discrimination. Furthermore, only two of Lashley's cases involved temporal destructions and by no means all of this region (6). Wiley (20), on the other hand, found auditory localization in the temporal region which is comparable to that found by Lashley for visual localization in the occipital region.

Bartley (1) writes in a similar vein. Local areas of the brain represent "peaks in transcortical gradients of some sort, but cannot be said to have specificity of function."

Lashley has reported an extensive series of experiments which substantiate a field theory of cortical activity. In interpreting the results of his experiments, Lashley presents three theoretical principles, namely, equipotentiality, mass action, and dynamic equilibrium of brain areas.

He shows that behavior disturbances are roughly proportional to loss of cortical tissue but continues to postulate, to a certain extent, localization of function in order to account for the fact that injury to the occipital pole was more critical for brightness and form discrimination than injuries elsewhere. Lashley has not made adequate use of the principles with which he began. The present concept of the bipolar distribution of energy adequately explains the results of the cortical experimentation carried out by Lashley. A given area derives its function from its relation to the field as a whole. When a loss of the visual cortex destroys vision it means only that some of the energy necessary for this performance is lacking, and as a consequence the activity will not take place. This interpretation does not mean that the activity depended on this area alone or upon this area more than upon the brain as a whole. It is necessary to suppose only that sufficient amounts of energy necessary to carry out form discrimination no longer exist at the pole. At the same time, the most complicated visual function depends just as much upon the anterior pole as upon the posterior pole and in fact upon the entire transcortical gradient.

It means that successively larger amounts of tissue must be removed in order to produce the same effect, the farther down the gradient the lesion is made. In other words, if 10 per cent of the cortex, removed at the visual pole, were sufficient to destroy form vision, that 10 per cent might represent, say, 20 per cent of the energy available in the whole cortex for visual response. To destroy this same amount at the lower end of the gradient might require a lesion covering 30 per cent of cortical area, because of the lower degree of concentration of cortical energy, in that region, with respect to visual functions.

The results obtained from the work on handedness furnish little support to this hypothesis. At the "peak of a gradient" 4 per cent destructions abolish it or at least render it nonfunctional, i.e., the animals transfer. Destructions approximating 50 per cent of a hemisphere not involving the "peak" do not influence the gradient, i.e., the animals do not transfer. How large must such destructions be in order to affect the gradient?

Presumably gradients vary in their steepness or strength. Individuals with strong preferences for one hand would possess especially steep gradients. Then as soon as destructions, even if very gross, were removed ever so little from the steep character

they could not involve enough of the remainder of the gradient to alter the preference. Such cases might involve, say, 90 per cent destructions but the animal could show the same preference, not as strongly as previously, but sufficiently to manifest an exclusive use of one hand. However, ambidextrous cases presumably have less steep gradients. Then destructions not involving the steepest part of the gradient forcing an exclusive preference for one hand, would result in a more or less increase in the preference for the hand whose associated gradient is not affected.

There are five cases which exhibited ambidexterity throughout the observations before the operation. One case, No. 54, showed complete transfer. Let us assume that the steep character of the gradient was abolished. One case, No. 15, showed delayed transfer. We can assume that a steep part of the gradient was affected by a spread in destruction. One case, No. 53, showed a tendency to transfer at first, and then a tendency to recover. His gradients were quite variable, and make interpretation difficult.

This leaves us with two cases, Nos. 16 and 52, in which the operation had no apparent effect on the handedness. Can we be sure of this? Let us consider them more carefully. No. 52 used his right hand about 70 per cent of the time before the operation. A destruction of 2.3 per cent in the left cortex (levels 9 to 14) occurred. He thereupon used his right hand 66 per cent of the time. We have interfered with a less steep portion of the gradient ever so little and slight effects are to be seen! Consider the other case. No. 16 used his right hand 55 per cent of the time before the operation. A destruction of 18.3 per cent in the left cortex (levels 9 to 23) occurred. He thereupon used his right hand 68 per cent of the time. A gross destruction in a less steep portion of the gradient has made it steeper! Thus, with only two cases which may be regarded as crucial, we already find one which cannot be explained by the gradient hypothesis without making further assumptions.

If, on the other hand, we assume that handedness depends on the functioning of a local area, we would expect no interference from destructions outside this area, no matter how gross such destructions might be. This turns out to be the case within the limits tested in this experiment. Destructions which render this total area non-functional lead to complete transfer. Destructions partially involving the area have effects commensurate with the extent of the invasion. Very slight invasions may result in no manifestations of transfer whatsoever. As the degree of invasion increases, tendencies to transfer are shown whose ultimate result may be complete transfer. We can conceive of such complete transfers as being partially due to the practice which the non-preferred hand gets. Evidence that such practice is effective can be seen in animal No. 10 who was given forced reëducation with lasting effects upon his preference. The loss of facilitation in the preferred hand from the partially invaded area can account for the occasional use of the non-preferred hand.

It is more difficult to account for cases which recover the use of their hands. One such case was noted in the preliminary report (16). Similar cases among animals studied in this report are Nos. 34 and 37. In No. 34, effects are noticed in the first three observation periods, after which there was almost complete recovery. With the exception of one day thereafter she used the affected hand exclusively. In No. 37, effects of the operation were noted in the first four observation periods. Thereafter his recovery was complete. Other cases showing a tendency to recovery, but which was never complete, are Nos. 46 and 53. It is to be noted that these recovery cases did not show complete transfer in the early observation periods after the operation. The recoveries take place soon after reobservation begins. is no case of spontaneous recovery after complete transfer which lasted throughout the first week of reobservation. Whether these temporary disturbances are due to diaschisis effects, to the restoration of facilitation within the critical area, or to undetermined factors remains unknown.

Having said so much in favor of localization of function, there remain its limitations to point out. While the cases reported above indicate localization, obviously we are no closer to understanding just what has gone on in the localized center under discussion. This fact cannot be too greatly emphasized. After

knowing that a local area is concerned in a given reaction, all we know is "where," we know nothing about "how."

Nor is this all, although it is the most important criticism against the doctrine. To have localized a "handedness area" in the cortex is not to say that this is the only local area concerned with the trait. While we uncovered no evidence that extrapyramidal systems play a part (for example, evidence from wisespread destructions outside the critical area), it may be that they do in a way which prevents their manifestation under our particular conditions. Other systems which might be involved include those of the spinal cord and medulla, the cerebellum, and the corpus striatum (Wilson (22)). What part these systems play in handedness can only be determined by future research.

SUMMARY AND CONCLUSIONS

This research on handedness has been concerned wholely with the rat. No attempt has been made to reason analogously for the human nor to fit the facts regarding the human, in so far as they are known, to the results obtained in this investigation. The reader must bear in mind that the conclusions apply only to the rat and not to human beings. If he is interested in comparisons he may refer to Downey (3) for a recent summary of the facts of human handedness. He may, however, hold to my belief, namely, that the time has come for those who advance hypotheses concerning the cause of causes of human handedness to present better evidence than they have in the past and, whenever possible, to substantiate this evidence by experimental verification, if not in human beings, at least in the rat.

The conclusions formulated below seem to be warranted from the facts established in this study:

- 1. Three varieties of handedness are found in the rat, namely, right handedness, left handedness, and ambidexterity.
- 2. It is difficult to determine the true incidence of each of these varieties but it is probable that right and left handedness occur in about equal numbers and that ambidexterity occurs much less frequently than either of the other conditions.
 - 3. Handedness is an enduring and stable characteristic in the rat.
 - 4. It is relatively complex, in that animals are not necessarily

consistent in different situations in their preferential use of the hands.

- 5. Practice, i.e., chance and previous experience, cannot altogether account for the trait in that ambidextrous animals do not seem to be fixated to an exclusive preference for one hand by a greater amount of practice with that hand.
- 6. If handedness is inherited, it is not according to a simple Mendelian formula, but in some complex way not yet revealed after seven generations of inbreeding.
- 7. It is not conditioned by the mode of origin of the carotid arteries.
- 8. Regarding the position of the foetus, no factor could be found which might account for handedness.
- 9. It is not dependent upon the dominance of one eye over the other.
- 10. Cerebral mechanisms for handedness are rather definitely localized in the frontal area of the contralateral hemisphere.
- 11. This area may be located *roughly* by electrical stimulation of the brain which produces arm and hand movements.
- 12. Destructions in this area amounting to less than 4 per cent of the area of one hemisphere will lead to transfers in the preferential use of the hands.
- 13. These transfers appear to be permanent, i.e., they were present ten weeks after the operation.
- 14. Occasional "spontaneous" recoveries occur where the critical area has been invaded but not completely destroyed. These recoveries seem to occur soon after the operation, and where the transfer is not complete. They are difficult to explain.
- 15. Sometimes transfers are delayed and it is assumed in such cases that the destruction spread to include the critical area.
- 16. Destructions amounting to 50 per cent of one hemisphere will not affect the preferential use of the hands if the critical area is not involved.
- 17. Lesions in the homolateral hemisphere will not affect the preferential use of the hands.
- 18. Animals with destructions in the critical areas of both hemispheres continue to show a preference for one hand, indicating an asymmetrical mechanism which is extra-pyramidal, subcortical, or both.

- 19. Forced practice with the hand affected by a cerebral destruction reveals that reëducation is a definite possibility.
- 20. The results of cerebral destruction are more easily explicable in terms of the doctrine of localization than in terms of hypotheses denying localization.

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APPENDIX A
Records in food situation

1 TESTED		2 TESTED			3 TESTED			
Date	Re	sult	Date	Result		Date	Result	
	R	L		R	L	2500	R	L
4/26/30	2	48	4/26/30	0	50	4/ 1/30	7	43
4/28/30	0	50	4/28/30	0	50	4/ 7/30	4	46
4/29/30	0	50	4/29/30	0	50	4/8/30	0	50
4/30/30	0	50	4/30/30	0	50	4/ 9/30	1	49
5/ 1/30	0	50	5/ 1/30	0	50	4/10/30	0	50
5/ 2/30	0	50	5/ 2/30	0	50	4/11/30	0	50
5/ 3/30	0	50	5/ 3/30	0	50	4/12/30	2	48
5/ 5/30	0	50	5/ 5/30	0	50	4/14/30	0	50
5/ 6/30	0	50	5/ 6/30	0	50	4/15/30	0	50
5/ 7/30	0	50	5/ 7/30	0	50	4/19/30	0	50
5/8/30	0	50	5/ 8/30	0	50			1
5/ 9/30	0	50	5/ 9/30	0	50	Operated 4	,	
		5/10/30	0	50	Left Frontal			
Operated 5/1	.2/30		0 1 7 /	10 (00		TO TOWN	STED	
Left Frontal			Operated 5/	,		KEII	DELED	
To William	ESTED		Left Fronta	l		5/ 5/30	0	50
KET	ESTED		RETESTED			5/ 6/30	0	50
6/ 3/30	0	50	Kair	SIED		5/ 7/30	0	50
6/ 4/30	0	50	6/ 3/30	0	50	5/ 8/30	0	50
6/ 5/30	0	50	6/ 4/30	0	50	5/ 9/30	0	50
6/ 6/30	0	50	6/ 5/30	0	50	5/10/30	0	50
6/ 7/30	0	50	6/ 6/30	0	50	5/12/30	0	50
6/10/30	0	50	6/ 7/30	0	50	5/19/30	0	50
6/11/30	0	50	6/10/30	0	50	5/26/30	0	50
6/16/30	0	50	6/11/30	0	50	6/ 3/30	0	50
6/24/30	0	50	6/16/30	0	50	6/10/30	0	50
7/ 1/30	0	50	6/24/30	0	50	6/16/30	0	50
7/ 8/30	0	50	7/ 1/30	0	50			
7/15/30	0	50	7/8/30	0	50			
7/22/30	0	50	7/15/30	0	50			
-,,			7/22/30	0	50			

APPENDIX A—Continued

4 TESTED		5 TESTED			6 TESTED			
Date	Result		Date	Result		Date	Result	
Duto	R	L		R	L	2.000	R	I
4/28/30	0	50	6/14/30	50	0	4/ 3/30	48	2
4/29/30	0	50	6/16/30	50	0	4/4/30	50	0
4/30/30	0	50	9/26/30	50.	0	4/ 5/30	50	0
5/ 1/30	0	50	9/27/30	50	0	4/ 7/30	50	0
5/ 2/30	0	50	9/29/30	50	0	4/8/30	50	0
5/ 3/30	0	50	9/30/30	50	0	4/ 9/30	50	.0
5/ 5/30	0	50	10/ 1/30	50	0	4/10/30	50	0
5/ 6/30	0	50	10/ 2/30	50	0	4/11/30	50	0
5/ 7/30	0	50	10/ 3/30	50	0	4/12/30	50	0
5/ 8/30	0	50		1	1	4/14/30	50	0
5/ 9/30	0	50	Operated 11			4/19/30	50	0
5/10/30	0	50	Right Occip	oital		4/28/30	50	0
	1	<u> </u>				4/29/30	50	0
perated 5/12/30		RETESTED		4/30/30	50	0		
eft Frontal	and So	maes-	12/ 6/30	50	0	5/ 1/30	50	0
thetic	thetic		12/ 8/30	50	0	5/ 2/30	50	0
		12/ 9/30	50	0	5/ 3/30	50	0	
RETESTED		12/10/30	50	0	5/ 5/30	50	0	
6/ 3/30	0	50	12/10/30	50	0	5/ 6/30	50	0
6/ 4/30	0	50	12/11/30	50	0		1	
6/ 5/30	0	50	12/12/30	50	0	Operated 5,		
6/ 6/30	0	50	12/20/30	50	0	Right Fron	tal	
6/ 7/30	0	50	12/27/30	50	0			
6/10/30	0	50	1/ 3/31	50	0	RETI	ESTED	
6/11/30	0	50	1/10/31	50	0	6/ 3/30	50	0
6/11/30 $6/16/30$	0	50	1/17/31	50	0	6/ 4/30	50	0
6/24/30	0	50	3/ 2/31	50	0	6/ 5/30	50	0
7/ 1/30	0	50	0/ 2/01	30		6/ 6/30	50	0
7/ 8/30	0	50				6/10/30	50	0
7/15/30	0	50				6/16/30	50	0
7/22/30	0	50				6/17/30	50	0
., 22, 00						6/24/30	50	0
						7/ 1 30	50	0
						7/ 8/30	50	0
						7/15/30	50	0
						7/22/30	50	0

APPENDIX A-Continued

	7 TED		TES	8 TED			9 STED	
Date	Re	sult	Date	Re	sult	Date	Re	sult
	R	L		R	L	25400	R	L
4/ 1/30	0	50	2/26/30	0	50	4/1/30	2	48
4/ 3/30	0	50	2/28/30	0	50	4/ 3/30	0	50
4/4/30	0	50	3/ 4/30	0	50	4/4/30	0	50
4/ 5/30	0	50	3/ 7/30	0	50	4/ 5/30	0	50
4/ 7/30	0	50	3/11/30	0	50	4/10/30	0	50
4/8/30	0	50	3/14/30	0	50	4/11/30	0	50
4/ 9/30	0	50	3/20/30	0	50	4/12/30	0	50
4/10/30	0	50	3/22/30	0	50	4/14/30	0	50
4/11/30	0	50	4/4/30	0	50	4/15/30	0	50
4/12/30	0	50	4/ 5/30	0	50	4/19/30	0	50
4/14/30	0	50	4/ 7/30	0	50	0 114	/01 /00	<u> </u>
4/15/30	0	50	4/ 8/30	0	50	Operated 4		
4/19/30	0	50	4/ 9/30	0	50	Right Fron	tai	
Operated 4/2	1 /20		4/10/30	0	50	RETI	ESTED	
	*		4/11/30	0	50		l -	
Right Fronta	1		4/12/30	0	50	5/ 5/30	0	50
RETE	STED		4/14/30	0	50	5/ 6/30	0	50
F / F /00	1 0	1 50	4/15/30	0	50	5/ 7/30	0	50
5/ 5/30	0	50	4/19/30	0	50	5/ 8/30	0	50
5/ 6/30	0	50	Operated 4/2	21/30		5/ 9/30	0	50
5/ 7/30	0	50	Right Front			5/10/30	0	50
5/ 8/30 5/ 9/30	0	50				5/12/30 5/19/30	0	50 50
5/10/30	0	50	RETE	STED		5/19/30 5/26/30	0	50
5/19/30	0	50	5/ 5/30	3	47	6/3/30	0	50
5/26/30	42	8	5/ 6/30	0	50	6/10/30	0	50
5/27/30	42	8	5/ 7/30	0	50	0/10/50		50
5/27/30	34	16	5/ 8/30	0	50			
6/ 3/30	41	9	5/ 9/30	0	50			
6/ 4/30	40	10	5/10/30	. 0	50			
6/ 5/30	37	13	5/12/30	0	50			
6/ 6/30	48	2	5/19/30	0	50			
6/ 7/30	46	4	5/26/30	0	50			
6/10/30	43	7	6/ 4/30	0	50			
6/11/30	37	13	6/10/30	0	50			
6/13/30	43	7	6/16/30	0	50			
6/14/30	48	2						
6/16/30	48	2						
6/17/30	50	0						
6/18/30	50	0						
6/19/30	50	0						
6/20/30	50	0						
6/21/30	50	0						
6/23/30	50	0						
6/24/30	50	0						
7/ 1/30	50	0						
7/ 8/30	50	0						
7/15/30	50	0						
7/22/30	50	0						

APPENDIX A-Continued

	10 STED			11 STED		TE	12 STED	
Date	Re	esult	Date	Re	sult	Date	Re	sult
	R	L		R	L	2400	R	L
4/ 1/30	0	50	6/14/30	0	50	4/ 1/30	3	47
4/ 3/30	0	50	6/16/30	0	50	4/ 3/30	5	45
4/4/30	0	50	9/29/30	0	50	4/4/30	0	50
4/ 5/30	0	50	9/30/30	0	50	4/ 5/30	0	50
9/29/30	0	50	10/ 1/30	0	50	10/13/30	0	50
9/30/30	0	50	10/ 2/30	0	50	10/14/30	0	50
10/ 1/30	0	50	10/ 3/30	0	50		1	J
10/ 2/30	0	50	10/ 4/30	0	50	Operated 10		
10/ 3/30	0	50	10/ 7/30	0	50	Right Soma	aesthet:	ic
10/ 4/30	0	50		,	1	Dam	ESTED	
10/ 7/30		1	Operated 11			, and the state of	LSTED	1
0	24 /20	<u>'</u>	Right Front	al		11/ 5/30	50	0
Operated 10/2			RET	ESTED		11/ 6/30	50	0
Right Somaes	stnetic			1	1	11/ 7/30	50	0
RETE	STED		11/ 6/30	50	0	11/13/30	50	0
11/ 7/30	31	19	11/19/30	50	0	11/14/30	50	0
11/13/30	41	9	11/20/30	50	0	11/15/30	50	0
11/14/30	48	2	11/21/30	50	0	11/17/30	50	0
11/15/30	50	0	11/24/30	50	0	11/18/30	50	0
11/17/30	48	2	11/25/30	50	0	11/19/30	50	0
11/18/30	50	0	11/26/30	50	0	11/26/30	50	0
11/19/30	50	0	11/28/30	50	0	11/29/30	50	0
11/20/30	45	5	11/29/30	50	0	12/ 6/30	50	0
11/21/30	21	29	12/ 6/30	50	0	12/13/30	50	0
11/24/30	43	7	12/13/30	50	0	12/23/30	50	0
11/26/30	45	5	12/20/30	50	0	1/ 3/31	50	0
11/28/30	50	0	12/27/30	50	0	1/10/31	50	0
11/29/30	50	0	1/3/31	50	0	AFTER RE	ËDUCATIO	ON
12/ 6/30	50	0	1/10/31	50	0		1	
12/13/30	49	1	AFTER REİ	DUCATIO	N	1/16/31	45	5
12/20/30	45	5	1/10/01	1 1		1/17/31	50	0
12/27/30	44	6	1/16/31	50	0			
1/ 3/31	50	0	1/17/31	50	0			
1/10/31	44	6						
AFTER REË	DUCATIO	N						
1/16/31	5	45						
1/17/31	1	49						
1/19/31	1	49					1	
1/20/31	5	45						
1/21/31	3	47						
1/23/31	34	16						
1/27/31	24	26						
1/28/31	8	42						
1/31/31	40	10						
2/ 3/31	8	42						
2/ 7/31	16	34						
2/13/31	7	43						
2/21/31	15	35						
		00						
2/28/31 3/ 2/31	22 21	28 29					1	

APPENDIX A—Continued

TES	.3 red		1 TES				5 TED	
Date	Res	sult	Date	Res	sult	Date	Res	sult
25000	R	L	2400	R	L	15400	R	L
5/14/30	50	0	2/26/30	50	0	4/ 1/30	35	15
5/16/30	50	0	2/28/30	50	0	4/ 3/30	40	10
9/26/30	50	0	3/ 4/30	50	0	4/4/30	19	31
9/27/30	50	0	3/ 7/30	50	0	4/ 7/30	37	13
9/29/30	50	0	3/11/30	50	0	4/8/30	31	19
9/30/30	50	0	3/14/30	50	0	4/ 9/30	12	38
10/ 1/30	50	0	3/20/30	50	0	4/10/30	8	42
10/ 2/30	50	0	3/22/30	50	0	4/11/30	2	48
10/ 3/30	50	0	4/4/30	48	2	4/12/30	15	35
0	20 /20	<u></u>	4/ 5/30	50	0	4/14/30	7	43
Operated 11/2	22/30		4/ 7/30	50	0	4/15/30	6	44
Left Frontal			4/8/30	50	0	4/19/30	0	50
RETE	STED		4/ 9/30	50	0	Operated 4	/21 /20	
10/0/00	1 0	1 0	4/10/30	50	0	Right Fron		
12/ 6/30	0	0	4/11/30	50	0	Tught From		
12/ 8/30	0	0	4/12/30 4/14/30	50	0	RETI	ESTED	
12/ 9/30 12/10/30	0	0	4/14/30	50	0	5/ 5/30	10	40
12/10/30	0	0	4/19/50	30	, 0	5/ 6/30	5	45
12/11/30	0	0	Operated 4/2	21/30		5/ 7/30	3	47
12/13/30	0	0	Left Frontal			5/ 8/30	0	50
12/20/30	0	0				5/ 9/30	0	50
12/27/30	0	0	RETE	STED		5/10/30	0	50
1/ 3/31	0	0	5/ 5/30	50	0	5/12/30	37	13
1/10/31	0	0	5/ 6/30	50	0	5/13/30	38	12
1/17/31	0	0	5/ 7/30	50	0	5/14/30	20	30
-, -,			5/ 8/30	50	0	5/19/30	50	0
			5/ 9/30	50	0	5/26/30	50	0
			5/10/30	50	0	6/ 3/30	50	0
			5/12/30	50	0	6/ 4/30	50	0
			-5/19/30	50	0	6/ 5/30	50	0
			5/26/30	50	0	6/ 6/30	50	0
			6/ 3/30	50	0	6/ 7/30	50	0
			6/10/30	50	0	6/10/30	50	0
						6/16/30	50	0
						6/24/30	50	0
						7/ 1/30	50	0
						7/ 8/30	50	0
						7/15/30	50	0
						7/22/30	50	0

APPENDIX A—Continued

			APPENDIA	A—Con	unuea			
1 TES	6 TED		1 TES				8 TED	
Date	Re	sult	Date	Re	sult	Date	Re	sult
	R	L		R	L		R	L
2/26/30	43	7	4/4/30	0	50	6/13/30	0	50
2/28/30	50	0	4/ 5/30	0	50	6/14/30	0	50
3/4/30	34	16	4/6/30	0	50	1/16/31	0	50
3/ 7/30	37	13	9/26/30	0	50	1/17/31	0	50
3/11/30	28	22	9/26/30	0	50	1/19/31	0	50
3/14/30	36	14	9/27/30	0	50	1/20/31	0	50
3/20/30	28	22	l 	1		1/21/31	0	50
3/22/30	17	33	Operated 9/2			1/22/31/	0	50
4/4/30	20	30	Right Occipi	ital				1
4/ 5/30	16	34	RETE	STED		Operated 1/		
4/ 7/30	23	27		1		Right Occi	-	and
4/8/30	16	34	9/30/30	0	25	Temporal		
4/ 9/30	16	34	10/ 1/30	0	25	RETE	STED	
4/10/30	15	35	10/ 4/30	0	25			ı
4/11/30	21	29	10/18/30	0	50	2/ 5/31	0	50
4/12/30	24	26	10/20/30	0	50	2/ 6/31	0	50
4/14/30	33	17	10/21/30	0	50	2/ 7/31	0	50
4/15/30	42	8	10/22/30	0	50	2/ 9/31	0	50
0 1 1 1 /0:	1 /00	1	10/23/30	0	50	2/10/31	0	50
Operated 4/2			10/24/30	0	50	2/11/31	0	50
Left Somaest	hetic		10/25/30	0	50	2/12/31	0	50
RETE	STED		11/ 1/30	0	50	2/18/31	0	50
E / E /20	25	25	11/13/30	0	50	2/25/31	0	50
5/ 5/30		14	11/24/30	0	50	3/4/31	0	50
5/ 6/30	36 37	13	12/ 1/30	0	50	3/17/31	0	50
5/ 7/30 5/ 8/30	43	7	12/13/30	0	50	3/18/31	0	50
5/ 9/30	30	20	12/27/30	0	50			
5/10/30	14	36	1/ 3/31	0	50			
5/12/30	42	8						
5/13/30	46	4						
5/14/30	42	8						
5/15/30	44	6						
5/19/30	50	0						
5/26/30	18	32						
6/ 3/30	9	41						
6/ 4/30	18	32						
6/ 5/30	38	12						
6/ 6/30	34	16						
6/ 7/30	40	10						
6/10/30	47	3						
6/12/30	35	15						
0/12/00	00	10						

APPENDIX A—Continued

1 TES	9 TED			20 STED			21 STED	
Date	Res	sult	Date	Res	sult	Date	Res	sult
	R	L		R	L	Date	R	L
6/14/30	0	50	6/14/30	0	50	2/19/31	50	0
6/16/30	0	50	6/16/30	0	50	2/21/31	50	0
12/ 4/30	0	50	1/16/31	0	50	2/23/31	50	0
12/ 5/30	0	50	1/17/31	0	50	2/24/31	50	0
1/16/31	0	50	1/19/31	0	50	2/25/31	50	0
1/17/31	0	50	1/20/31	0	50	2/26/31	50	0
1/19/31	0	50	1/21/31	0	50	2/28/31	50	0
1/20/31	0	50	1/22/31	0	50	4/ 5/31	50	0
1/21/31	0	50				4/8/31	50	0
1/22/31	0	50	Operated 1/		1.00	0 4 1 4 /0 /91		
0 1 1 1/0	0 /04	-	Right Occip	oital an	d Tem-			1 03
Operated 1/2		m	poral			Left Occipi	tal and	d Tem-
Right Occipi	tal and	Tem-	RET	ESTED		poral		
poral			0/ 5/91	1 0	=0	RET	ESTED	
RETI	ESTED		2/ 5/31	0	50	4 /00 /01	1 50	1 0
0 / 7 /01	1 0	1 50	2/ 6/31	0	50	4/22/31	50	0
2/ 5/31	0	50	2/ 7/31	0	50	4/23/31	50	0
2/ 6/31	0	50	2/ 9/31	0	50	4/24/31	50 50	0
2/ 7/31	0	50	2/10/31	0	50	4/25/31	50	0
2/ 9/31	0	50	2/11/31 $2/12/31$	0	50	4/27/31 $4/28/31$	50	0
2/10/31	0	50	2/12/31 2/18/31	0	50	4/29/31	50	0
$\frac{2}{11}/31$ $\frac{2}{12}/31$	0	50	$\frac{2/16/31}{2/25/31}$	0	50	4/30/31	50	0
$\frac{2}{12}$	0	50	3/4/31	0	50	5/ 7/31	50	0
	0	50	3/17/31	0	50	5/14/31	50	0
9 /95 /21	U		3/18/31	0	50	5/21/31	50	0
2/25/31	1 0							U
3/4/31	0	50	3/10/31			, ,		0
, ,	0 0	50 50 50	3/10/31			5/28/31 6/ 3/31	50 50	0

APPENDIX A—Continued

			ALLENDIA	AC07				
2 TES				STED			24 STED	
Date	Re	sult	Date	Re	sult	Date	Re	sult
	R	L		R	L		R	L
2/19/31	50	0	3/ 6/31	50	0	9/22/30	0	50
2/20/31	50	0	3/ 7/31	50	0	9/23/30	0	50
2/21/31	50	0	3/ 9/31	50	0	9/24/30	0	50
2/23/31	50	0	3/10/31	50	0	9/25/30	0	50
2/24/31	50	0	3/17/31	50	0	9/26/30	0	50
2/25/31	50	0	3/18/31	50	0	9/27/30	0	50
2/26/31	50	0	3/19/31	50	0	9/29/30	0	50
2/28/31	50	0	3/20/31	50	0 -	1/ 5/31	0	50
3/27/31	50	0	3/27/31	50	0	1/ 6/31	0.	50
4/ 5/31	50	0	3/31/31	50	0	1/ 7/31	0	50
4/8/31	50	0			1		(- (- 1	
0 1 1 1 1 1	10.1	1	Operated 3/		rm.	Operated 1,		
Operated 4/8		200	Left Occipit	al and	Tem-	Right Stim	ulable	Area
Left Occipita	and	Tem-	poral			RETI	ESTED	
poral			RETI	ESTED				1
RETE	STED			1		1/21/31	0	50
	l		4/15/31	50	0	1/22/31	0	50
4/22/31	50	0	4/17/31	50	0	1/23/31	0	50
4/23/31	50	0	4/18/31	50	0	1/26/31	0	50
4/24/31	50	0	4/20/31	50	0	. 1/27/31	0	50
4/25/31	50	0	4/21/31	50	0	1/28/31	0	50
4/27/31	50	0	4/22/31	50	0	1/29/31	0 .	50
4/28/31	50	0	4/23/31	50	0	2/ 5/31	0	50
4/29/31	50	0	4/24/31	50	0	2/12/31	0	50
4/30/31	50	0	5/ 2/31	50	0	2/17/31	0	50
5/ 7/31	50	0	5/11/31	50	0	2/25/31	0	50
5/14/31	50	0	5/18/31	50	0	3/ 4/31	0	50
5/21/31	50	0	5/25/31	50	0			
5/28/31	50	0	6/ 1/31	50	0			
6/ 3/31	50	0						
6/ 8/31	50	0						

APPENDIX A—Continued

	25 STED		26 TES				27 STED	
Date	Res	sult	Date	Res	sult	Date	Re	sult
Date	R	L	2200	R	L	Dage	R	L
2/12/31	0	50	6/14/30	0	50	11/18/30	0	50
2/21/31	0	50	6/16/30	0	50	11/19/30	0	50
2/23/31	0	50	9/29/30	0	50	11/24/30	0	50
2/24/31	0	50	9/30/30	0	50	1/19/31	0	50
2/25/31	0	50	10/ 1/30	0	50	3/27/31	0	50
2/26/31	0	50	10/ 2/30	. 0	50	3/28/31	0	50
2/28/31	0	50	10/ 3/30	0	50	3/31/31	0	50
3/27/31	0	50	10/ 4/30	0	50	4/ 3/31	0	50
4/ 5/31	0	50	10/ 7/30	0	50	4/ 5/31	0	50
Operated 4/1	.3/31		Operated 11	/5/30		Operated 4/13/31		
Right Stimu	lable Ar	rea	Right Stimu	lable A	rea	Right Stim	ulable	Area
RET	ESTED		RETE	STED		RETI	ESTED	
4/27/31	0	50	11/20/30	0	50	4/27/31	0	50
4/28/31	0	50	11/21/30	0	50	4/28/31	0	50
4/29/31	0	50	11/24/30	0	50	4/29/31	0	50
4/30/31	0	50	11/25/30	0	50	4/30/31	0	50
5/ 2/31	0	50	11/26/30	0	50	5/ 2/31	0	50
5/ 4/31	0	50	11/28/30	0	50	5/ 4/31	0	50
5/ 5/31	0	50	11/29/30	0	50	5/ 5/31	0	50
5/12/31	0	50	12/ 6/30	0	50	5/12/31	0	50
5/19/31	0	50	12/13/30	0	50	5/19/31	0	50
5/26/31	0	50	12/23/30	0	50	5/26/31	0	50
6/ 3/31	0	50	12/27/30	0	50	6/ 3/31	0	50
6/10/31	0	50	1/ 3/31	0	50	6/10/31	0	50

APPENDIX A—Continued

	STED			9 TED	TES			28 TES	
sult	Re	Date	sult	Res	Date	sult	Res	Date	
L	R	Date	L	R	Date	L	R	Dave	
0	50	6/13/30	0	50	5/13/30	50	.0	9/23/30	
0	50	6/14/30	0	50	5/14/30	50	0	9/24/30	
0	50	10/14/30	0	50	10/18/30	50	0,	9/25/30	
0	50	10/15/30	0	50	10/20/30	50	0	9/26/30	
0	50	10/16/30	0	50	10/21/30	50	0	9/27/30	
0	50	10/17/30	0	50	10/22/30	50	0	9/29/30	
0	50	10/18/30	0	50	10/23/30	50	0	1/19/31	
. 0	50	10/20/30	0	50	10/24/30	50	0	3/27/31	
0	50	10/21/30	0	50	10/25/30	50	0	4/ 5/31	
0	50	10/22/30	Operated 11/19/30				791		
)	1 /10 /20	0		19/30	Left Frontal	10.0	*	perated 4/13	
	, ,	Operated 1	Left Frontai				ight Stimulable Area		
rea	able A	Left Stimul		STED	RETE		STED	RETE	
	ESTED	RETE	50	0	12/ 3/30	50	0	4/27/31	
5	45	12/ 3/30	50	0	12/ 4/30	50	0	4/28/31	
0	50	12/ 4/30	50	0	12/ 5/30	50	0	4/29/31	
ő	50	12/ 5/30	50	0	12/ 6/30	50	0	4/30/31	
14	36	12/ 6/30	50	0	12/ 8/30	50	0	5/ 2/31	
4	46	12/ 8/30	50	0	12/ 9/30	50	0	5/ 4/31	
0	50	12/ 9/30	50	0	12/10/30	50	0	5/ 5/31	
7	43	12/10/30	50	0	12/11/30	50	0	5/12/31	
5	45	12/11/30	50	0	12/12/30	50	0	5/19/31	
3	47	12/12/30	50	0	12/13/30	50	0	5/26/31	
22	28	12/12/30	50	0	12/20/30	50	0	6/ 3/31	
27	23	12/13/30	50	0	12/27/30	50	0	6/10/31	
29	21	12/15/30	50	0	1/ 3/31				
39	11	12/16/30	50	0	1/10/31				
50	0	12/17/30	50	0	1/17/31				
49	. 1	12/18/30	- 1						
44	6	12/20/30						and a second	
50	0	12/24/30							
48	2	12/26/30							
38	12	12/27/30							
45	5	12/29/30							
46	4	12/30/30							
50	0	12/31/30							
45	5	1/ 2/31							
50	0	1/ 3/31							
48	2	1/10/31							
50	0	1/17/31							
50	0	1/24/31							
49	1	1/31/31							
50	0	2/ 9/31							

APPENDIX A—Continued

	STED		35 TES				3 TED	
Date	Res	sult	Date	Re	sult	Date	Rea	sult
2400	R	L		R	L	Date	R	L
9/22/30	49	1	9/26/30	50	0	9/23/30	0	50
9/23/30	50	0	9/27/30	50	0	9/24/30	0	50
9/24/30	50	0	9/29/30	50	0	9/25/30	1	49
9/25/30	50	0	9/30/30	50	0	9/26/30	. 2	48
9/26/30	50	0	10/ 1/30	50	0	9/27/30	0	50
9/27/30	50	0	10/ 2/30	50	0	9/29/30	0	50
9/29/30	50	0	10/ 3/30	50	0	9/30/30	0	50
11/17/30	50	0	3/27/31				0	50
11/22/30	50	0	Operated 11/7/30 4/ 5/31 0				0	50
	-		Left Stimula	ble Ar	ea			1
Operated 11/	,		RETE	STED		Operated 4,	,	
Left Stimula	ble Are	a	- KETE			Right Circu	ımsecti	ion
RETI	ESTED		11/21/30	0	50	RETI	ESTED	
	1	1	11/24/30	0	50		1	1 .
11/29/30	1	3	11/25/30	0	50	4/27/31	16	34
12/ 6/30	47	3	11/26/30	0	50	4/28/31	20	30
12/8/30	47	3	11/28/30	0	50	4/29/31	42	8
12/ 9/30	50	0	11/29/30	0	50	4/29/31	11	39
12/10/30	50	0	12/ 1/30	0	50	4/30/31	45	5
12/11/30	50	0	12/ 6/30	0	50	5/ 2/31	50	0
12/12/30	50	0	12/13/30	0	50	5/ 4/31	50	0
12/12/30	50	. 0	12/20/30	0	50	5/ 5/31	50	0
12/20/30	50	0	12/27/30	0	50	5/12/31	50	0
12/27/30	50	0	1/ 3/31	0	50 .	5/19/31	50	0
1/ 3/31	50	0	1/10/31	0	50	5/26/31	50	0
1/10/31	50	0	AFTER REI	ė DIIC A TIC	N	6/ 3/31	48	2
1/17/31	50	0	AFTER REI	, DUCATIC	1	6/10/31	50	0
3/2/31	50	0	1/16/31	0	50			
			1/17/31	0	50			

APPENDIX A—Continued

3 TEST				STED			36 STED	
Date	Re	sult	Date	Re	sult	Date	Re	sult
- 400	R	L		R	L		R	L
11/25/30	4	46	11/20/30	1	49	9/23/30	50	. 0
11/26/30	0	50	11/25/30	1	49	9/24/30	50	0
3/27/31	0	50	11/26/30	0	50	9/25/30	6	0
3/28/31	0	50	3/27/31	0	50	9/26/30	50	0
3/31/31	0	50	3/28/31	0	50	9/27/30	50	0
4/3/31	0	50	3/31/31	0	50	9/29/30	50	. 0
4/ 5/31	0	50	4/-3/31	0	50	9/30/30	50	0
	1)	4/ 5/31	0	50	1/ 3/31 50		0
Operated 4/1	,				1 .	1/ 5/31 50		0
Right Circum	nsection	n	Operated 4/	,				1
RETE	ESTED		Right Circu	\mathbf{m} section	on	Operated 1,		
	1		RET	ESTED		Left Circun	nsectio	n
4/27/31	15	35		1	1	RETI	ESTED	
4/28/31	17	33	4/27/31	0	50		1	
4/29/31	49	1	4/28/31	0	50	1/21/31	0	50
4/30/31	0	50	4/29/31	1	49	1/22/31	0	50
5/ 2/31	0	50	4/30/31	0	50	1/23/31	0	50
5/ 4/31	0	50	5/ 2/31	0	50	1/26/31	0	50
5/ 5/31	0	50	5/ 4/31	1	49	1/27/31	0	50
		417	E/E/91	0	50	1/28/31	0	50
5/12/31	3	47	5/ 5/31	0	00	-//	_	
5/12/31 5/19/31	3	50	5/12/31	1	49	1/29/31	0	50
, ,	1	1		1		1 ' '	0	50 50
5/19/31	0	50	5/12/31	1	49	1/29/31		
5/19/31 5/26/31	0	50 50	5/12/31 5/19/31	1 16	49 34	1/29/31 2/ 5/31	0	50
5/19/31 5/26/31 6/ 3/31	0 0 0	50 50 50	5/12/31 5/19/31 5/19/31	1 16 16	49 34 34	1/29/31 2/ 5/31 2/12/31	0	50 50
5/19/31 5/26/31 6/ 3/31	0 0 0	50 50 50	5/12/31 5/19/31 5/19/31 5/26/31	1 16 16 24	49 34 34 26	1/29/31 2/ 5/31 2/12/31 2/18/31	50 6 50 50 50 50 50 50 50 50 50 0 0 0 0	50 50 50

APPENDIX A—Continued

	57 STED		38 TES				9 TED	
Date	Res	sult	Date	Res	sult	Date Result		sult
	R	L		R	L	2400	R	L
9/23/30	50	0	9/23/30	48	2	6/13/30	0	50
9/24/30	50	0	9/24/30	50	0	6/14/30	0	50
9/25/30	50	0	9/25/30	50	0	1/16/31	0	50
9/26/30	50	0	9/26/30	50	0	1/17/31	0	50
9/27/30	50	0	9/27/30	50	0	1/19/31	0	50
9/29/30	50	0	9/29/30	50	0	1/23/31	0	50
9/30/30	50	0	9/30/30	50	0	1/27/31	0	50
1/ 3/31	50	0	1/ 3/31	50	0			
1/ 5/31	50	0	1/ 5/31	50	0	Operated 1/27/31		
				1	(Bilateral		
Operated 1/5			Operated 1/s	,		RETI	ESTED	
Left Circums	section		Left Circum	section			1	1
RET	ESTED		RETE	STED		2/10/31	0	50
	1			Ī	1	2/11/31	0	50
1/19/31	45	5	1/19/31	50	0	2/12/31	0	50
1/21/31	40	10	1/21/31	35	15	2/13/31	0	50
1/22/31	45	5	1/22/31	35	15	2/14/31	0	50
1/23/31	47	3	1/23/31	3	47	2/16/31	0	50
1/26/31	50	0	1/26/31	0	50	2/18/31	0	50
1/27/31	50	0	1/27/31	0	50	2/25/31	0	50
1/28/31	50	0	1/28/31	0	50	3/ 4/31	0	50
2/4/31	50	0	2/ 4/31	0	50	3/17/31	0	50
2/11/31	50	0	2/11/31	0	50	3/18/31	0	50
2/18/31	50	0	2/18/31	0	50	3/25/31	0	50
2/25/31	50	0	2/25/31	0	50			
3/ 4/31	50	0	3/ 4/31	0	50			

APPENDIX A—Continued

	10 STED			11 STED			42 STED		
Date	Re	sult .	Date	Re	sult	Date	Re	sult	
Davo	R	L	2400	R	L	2400	R	L	
6/13/30	0	50	6/14/30	0	50	11/20/30	50	0	
6/14/30	0	50	6/16/30	0	50	11/25/30	50	0	
1/16/31	0	50	1/16/31	0	50	11/26/30	50	0	
1/17/31	0	50	1/17/31	0	50	3/27/31	50	0	
1/19/31	0	50	1/19/31	0	50	3/28/31	50	0	
1/23/31	0	50	1/20/31	0	50	3/31/31	50	0	
1/27/31	0	50	1/23/31	0	50	4/ 3/31	50	0	
	1)	1/26/31	0	50	4/ 5/31 50			
Operated 1/2 Bilateral	7/31		1/27/31	0	50	4/ 8/31 50			
	ESTED		Operated 1/ Bilateral	27/31		Operated 4/8/31 Bilateral			
2/10/31	0	50	RET	ESTED		RET	ESTED		
$\frac{2}{11}/31$ $\frac{2}{12}/31$	0	50	2/10/31	5	45	4/22/31	0	0	
$\frac{2}{12}/31$ $\frac{2}{13}/31$	0	50	2/10/31	0	50	4/23/31	5	45	
$\frac{2}{13}$	0	50	2/11/31 2/12/31	0	50	4/24/31	0	50	
$\frac{2}{16}$	0	50	2/13/31	0	50	4/25/31	0	50	
2/18/31	0	50	2/14/31	0	50	4/27/31	0	50	
2/25/31	0	50	2/16/31	0	50	4/28/31	. 0	50	
3/4/31	0	50	2/18/31	0	50	4/29/31	0	50	
3/17/31	0	50	2/25/31	0	50	4/30/31	o	50	
3/18/31	0	50	3/4/31	0	50	5/ 7/31	0	50	
3/25/31	0	50	3/17/31	0	50	5/14/31	o	50	
2/ -2/ 22			3/18/31	0	50	5/21/31	o	50	
			3/25/31	0	50	5/28/31	ő	50	
						6/ 3/31	0	50	
						6/ 8/31	0	50	

APPENDIX A—Continued

43 TESTED				14 STED		45 TESTED		
Date	Res	sult	Date	Re	sult	Date		
2000	R	L	Dutte	R	L	Dave	R	L
3/ 3/31	50	0	3/ 9/31	50	0	3/ 2/31	50	
3/ 6/31	50	0.	3/10/31	50	0	3/ 3/31	50	
3/ 9/31	50	0	3/17/31	50	0	3/ 6/31	50	
3/10/31	50	0	3/18/31	50	0	3/ 9/31	50	(
3/17/31	50	0	3/19/31	50	0	3/10/31	50	(
3/18/31	50	0	3/20/31	50	0	3/17/31	50	(
3/19/31	50	0	3/23/31	50	0	3/18/31	50	
3/27/31	50	0	3/27/31	50	0	3/19/31	50	1
3/31/31	50	0	3/31/31	50	0	3/27/31	50	(
		-				50	(
perated 3/31/31			Operated 3/	'31/31				1
ilateral			Bilateral			Operated 3	/31/31	
RET	ESTED		RET	ESTED	Bilateral			
4/15/31	0	0	4/15/31	50	0	RET	ESTED	
4/17/31	50	0	4/17/31	50	0	4/15/31	39	11
4/18/31	50	0	4/18/31	50	0	4/17/31	50	(
4/20/31	48	2	4/20/31	50	0	4/18/31	50	
4/21/31	50	0	4/21/31	50	0	4/20/31	50	
4/22/31	50	0	4/22/31	50	0	4/21/31	50	
4/23/31	50	0	4/23/31	50	0	4/22/31	50	
4/24/31	50	0	4/24/31	50	0	4/23/31	50	(
5/ 2/31	49	1	5/ 2/31	50	0	4/24/31	50	
5/11/31	50	0	5/11/31	50	0	5/ 2/31	50	(
5/18/31	50	0	5/18/31	50	0	5/11/31	50	(
5/25/31	50	0	5/25/31	50	0	5/18/31	50	(
6/ 1/31	50	0	6/ 1/31	50	0	5/25/31	50	(
' '						6/ 1/31	50	(

APPENDIX A—Continued

			ALLENDIA	A-001	ueu				
	46 TESTED			7 TED		48 TESTED			
Date	Re	sult	Date	Re	sult	Result Date			
2400	R	L	Lanc	R	L		R	L	
11/18/30	0	50	2/19/31	0	50	3/ 9/31	0	50	
11/19/30	0	50	2/20/31	0	50	3/10/31	0	50	
11/24/30	0	50	2/21/31	0	50	3/17/31	0	50	
3/27/31	0	50	2/23/31	0	50	3/18/31	0	50	
3/28/31	0	50	2/24/31	0	50	3/19/31	0	- 50	
3/31/31	0	50	2/25/31	0	50	3/20/31	0	50	
4/3/31	0	50	2/26/31	0	50	3/23/31	0	50	
4/ 5/31	0	50	2/28/31	0	50	4/ 3/31	0	50	
	1	1	3/27/31	0	50	4/ 5/31	0	50	
Operated 4/1	,		4/ 5/31	0	50	0 + 14	/10 /01	!	
Right Fronta	.1		Operated 4/13/3 Operated 4/13/31 Right Frontal						
Superficial						Right Frontal Superficial			
RETE	STED			Right Frontal					
4/27/31	28	22	Superficial			RETI	ESTED		
4/28/31	40	10	RETE	STED		4/27/31	45	5	
4/29/31	50	0	4/27/31	49	1	4/28/31	48	2	
4/30/31	31	19	4/28/31	50	0	4/29/31	50	0	
5/ 2/31	38	12	4/29/31	50	0	4/30/31	50	0	
5/ 4/31	35	15	4/30/31	50	0	5/ 2/31	50	0	
5/ 5/31	43	7	5/ 2/31	50	0	5/ 4/31	50	0	
5/12/31	50	0	5/ 4/31	50	0	5/ 5/31	50	0	
5/19/31	50	0	5/ 5/31	50	0	5/12/31	50	0	
5/26/31	50	0	5/12/31	50	0	5/12/31	50	0	
6/ 3/31	47	3	5/19/31	50	0	5/26/31	50	0	
6/10/31	41	9	5/26/31	50	0	6/3/31	50	0	
6/11/31	40	10	6/3/31	50	-0	6/10/31	50	0	
6/11/31	34	16	6/10/31	50	0	0/10/01	00		
0/11/01	O.T.	10	0/10/31	00	0		1		

APPENDIX A—Continued

49 TESTED			50 TES			51 TESTED			
Date	Re	sult	Date	Re	sult	Date Result			
	R	L		R	L	Danc	R	L	
9/22/30	50	0	9/22/30	48	2	11/20/30	17	33	
9/23/30	50	0	9/23/30	50	0	11/26/30	20	30	
9/24/30	50	0	9/24/30	50	0	1/ 7/31	25	25	
9/25/30	50	0	9/25/30	50	0	1/8/31	48	2	
9/26/30	50	0	9/26/30	50	0	1/ 9/31	50	0	
9/27/30	50	0	9/27/30	50	0	1/10/31	50	0	
9/29/30	50	0	9/29/30	50	0	1/12/31	50	0	
1/ 3/31	50	0	1/ 3/31	50	0	1/13/31	50	0	
1/ 5/31	50	0	1/ 5/31	50	0	1/14/31	50	0	
Operated 1/5	/31		Operated 1/8	5/31		Operated 1	/14/31		
Left Frontal	,		Left Frontal	,		Left Fronts			
Superficial			Superficial			Superficial			
RETI	ESTED	RETE	RETESTED			ESTED			
1/21/31	9	41	1/21/31	50	0	1/28/31	50	0	
1/22/31	0	50	1/22/31	50	0	1/29/31	50	0	
1/23/31	0	50	1/23/31	50	0	1/30/31	50	0	
1/26/31	0	50	1/26/31	50	0	1/31/31	50	0	
1/27/31	0	50	1/27/31	50	0	2/ 2/31	50	0	
1/28/31	0	50	1/28/31	50	0	2/ 3/31	50	0	
1/29/31	0	50	1/29/31	50	0	2/ 4/31	50	0	
2/ 5/31	0	50	2/ 5/31	50	0	2/11/31	50	0	
2/12/31	0	50	2/12/31	50	0	2/18/31	50	0	
2/18/31	0	50	2/18/31	50	0	2/25/31	50	0	
2/25/31	0	50	2/25/31	50	0	3/ 4/31	43	7	
3/ 4/31	0	50	3/ 4/31	50	0	3/17/31	45	5	
						3/18/31	40	10	
						3/19/31	50	0	
						3/20/31	48	2	

APPENDIX A—Continued

	52 TESTED			3 TED		54 TESTED			
-	Re	sult		Re	sult		Res	Result	
Date	R	L	Date	R	L	Date	R	L	
11/20/30	26	24	11/17/30	30	20	11/20/30	33	17	
11/25/30	15	35	11/18/30	30	20	11/25/30	25	25	
11/26/30	25	25	11/19/30	19	31	11/26/30	30	20	
1/8/31	49	1	11/25/30	22	28	12/27/30	31	19	
1/ 9/31	46	4	1/8/31	15	35	1/ 8/31	38	12	
1/10/31	42	8	1/ 9/31	2	48	1/ 9/31	23	27	
1/12/31	44	6	1/10/31	14	36	1/10/31	19	31	
1/13/31	40	10	1/12/31	6	44	1/12/31	20	30	
1/14/31	26	24	1/13/31	4	46	1/13/31	19	31	
			1/14/31	5	45	1/14/31	20	30	
Operated 1/14	*				1		l		
Left Somaestl	hetic		Operated 1/	14/31		Operated 1	/14/31		
Superficial			Right Front	al		Right Fron	tal		
RETES	STED		Superficial			Superficial			
1/28/31	18	32	RETE	STED		RETESTED			
1/29/31	22	28	1/28/31	50	0	1/28/31	50	0	
1/30/31	20	30	1/29/31	46	4	1/29/31	50	0	
1/31/31	14	36	1/30/31	29	21	1/30/31	50	0	
2/ 2/31	26	24	1/31/31	30	20	1/31/31	50	0	
2/ 3/31	35	15	2/ 2/31	36	14	2/ 2/31	50	0	
2/4/31	41	9	2/ 3/31	40	10	2/ 3/31	50	0	
2/11/31	43	7	2/ 4/31	48	2	2/4/31	50	0	
2/18/31	40	10	2/11/31	49	1	2/11/31	50	0	
2/25/31	45	5	2/18/31	50	0	2/18/31	50	0	
3/ 4/31	43	7	2/25/31	50	0	2/25/31	50	0	
3/17/31	41	9	3/ 4/31	50	0	3/ 4/31	50	0	
3/18/31	17	33	3/17/31	49	1	3/17/31	50	0	
3/19/31	40	10	3/18/31	31	19	3/18/31	50	0	
3/20/31	48	2	3/19/31	7	43	3/19/31	50	0	
			3/20/31	30	⁻⁵ 20	3/20/31	50	0	
			3/23/31	35	15				
			3/24/31	20	30				
			3/25/31	42	8				
			3/26/31	46	4				
			4/6/31	49	1				
			4/11/31	43	7				
			4/17/31	45	5				
			4/23/31	21	29				
			4/23/31	11	39				
			4/30/31	24	26				
			5/16/31	28	22				
			6/11/31	11	39				
			0/11/31		00				
			6/11/31 6/11/31	21 36	29 14				

APPENDIX A—Concluded

55 TESTED			6 TED	59 TESTED					
Date	Res	sult	Date	Result		Date	Result		
- 400	R	L	2400	R	L	2000	R	L	
4/ 1/30	50	0	9/22/30	0	50	11/17/30	50	0	
4/ 3/30	50	0	9/23/30	0	50	11/18/30	50	0	
4/4/30	50	0	9/24/30	0	50	11/19/30	50	0	
4/ 5/30	50	0	9/25/30	0	25	11/25/30	50	0	
5/ 1/30	50	0	9/26/30	0	50	2/19/31	50	0	
5/ 2/30	50	0	9/27/30	0	50	2/23/31	50	0	
5/ 3/30	50	0	9/29/30	0	50	2/24/31	50	0	
5/ 5/30	50	0	1/5/31	0	50	2/25/31	50	0	
5/ 6/30	50	0	1/ 7/31	0	50	2/26/31	50	0	
5/ 7/30	50	0	5/14/31	0	50	2/28/31	50	0	
5/8/30	50	0	6/ 1/31	0	50	3/23/31	50	0	
10/14/30	50	0		1		3/27/31	50	0	
10/15/30	50	0		7 STED		6/25/31	50	0	
10/16/30	50	0				- 00			
10/17/30	50	0	Date	Res	sult	60 TESTED			
10/18/30	50	0	Dave	R L			1		
10/20/30	50	0	44 (47 (00	-	40	Date	Result		
10/21/30	50	: 0	11/17/30	4	46	240	R	L	
10/22/30	50	. 0	11/18/30	5	45	0 /00 /00	40	1	
0 4 1 11 /6	20 /20		11/19/30	1	49	2/26/30	49 50	1 0	
Operated 11/2	22/30		11/25/30	0	50 49	2/28/30 3/4/30	47	3	
Left Frontal			11/26/30	1 0	50	3/ 7/30	47	3	
Trephine Onl	У		6/25/31	0	1 00	3/11/30	48	2	
RETE	STED		5	58			36	14	
10/0/20	1 =0			STED		3/14/30 3/20/30	46	4	
12/ 6/30	50	0		Re	sult	3/22/30	43	7	
12/ 8/30	50	0	Date		1 -	1/16/31	35	15	
12/ 9/30	50	0		R	L	1/17/31	33	17	
12/10/30	50	0	11/20/30	50	0	1/19/31	35	15	
12/11/30	50	0	11/25/30	50	0	1/23/31	40	10	
12/12/30	50	0	11/26/30	50	0	$\frac{1/25/31}{1/27/31}$	36	14	
12/13/30	50	0	3/23/31	50	0	$\frac{1/27/31}{6/25/31}$	35	15	
12/20/30	50	0	3/27/31	50	0	0/20/01	00	10	
12/27/30	50	0	8/19/31	50	0				
1/ 3/31	50	0	10/ 5/31	50	0				
1/10/31	50	0	10/ 7/31	50	o o				
1/17/31	50	0	12/ 5/31	50	0				
1/27/31	50	0	22/ 0/01	00					

APPENDIX B Records in latch box

1 TESTI	ED		3 TESTED			14 TEST			31 TESTED				
	Re	sult		Result			Result		Result			Result	
Date	R	L	Date	R	L	Date	R		Date	R	L		
5/ 6/30	6	0	4/10/30	6	0	4/15/30	6	0	11/ 6/30	6	0		
5/ 7/30	6	0	4/11/30	6	0	4/16/30	6	0	11/ 7/30	6	0		
5/ 8/30	6	0	4/12/30	6	0	4/17/30	6	0	11/13/30	6	0		
5/ 9/30	6	0	4/14/30	6	0	4/18/30	6	0	11/14/30	6	0		
5/10/30	6	0	4/15/30	6	0	4/19/30	6	0	11/15/30	6	0		
			4/16/30	6	0		1				1		
Operated 5/)	4/17/30	6	0	Operated		/30	Operated	,			
Left Fronta	1		4/18/30	6	0	Left Fron	ital			imu	lable		
RETEST	red		4/19/30	6	0	RETES	TED		Area				
6/ 3/30	0	6	Operated	4/21	/30	5/ 5/30	6	0	RETES	TED			
6/ 4/30	0	6	Left From	ntal		5/ 6/30	6	0	11/29/30	3	0		
6 /5/30	0	6	RETES			5/ 7/30	6	0	12/ 6/30	6	0		
6/ 6/30	0	6	NETE:	1 20		5/ 8/30	6	0	12/ 8/30	6	0		
6/ 7/30	0	6	5/ 5/30	6	0	5/ 9/30	6	0	12/ 9/30	6	0		
6/10/30	0	6	5/ 6/30	6	0	5/10/30	6	0	12/10/30	6	0		
6/11/30	0	6	5/ 7/30	6	0	5/12/30	6	0	12/11/30	6	0		
	1		5/ 8/30	6	0	6/10/30	6	0	12/12/30	6	0		
2 TEST	ED.		5/ 9/30	6	0				12/13/30	6	0		
1201.			5/10/30	6	0	15 TEST			12/27/30	6	0		
Date	Res	sult	5/12/30	6	0		1				1/17/31	6	0
Dave	R	L	6/10/30	6	0	Date	Re	sult	3/ 2/31	6	0		
5/ 7/30	6	0	6/16/30	6	0		R	L					
5/ 8/30	6	0	5		4/15/30	0	6						
5/ 9/30	6	0	TEST	ED		4/16/30	0	6					
5/10/30	6	0		Re	sult	4/17/30	0	6					
5/12/30	6	0	Date	R	L	4/18/30	0	6					
						4/19/30	0	6					
Operated 5/)	10/28/30	10/28/30 0 6									
Left Fronta	l		10/29/30	0	6	Operated	4/21	/30					
RETES'	red		10/30/30	0	6	Right Fro	ontal						
			10/31/30	0	6	RETES	TED						
6/ 3/30	2	3	11/ 1/30	0	6	F / F /90		1 0					
6/ 4/30	2	4	Operated	11/2	22/30	5/ 5/30	0	6					
6/ 5/30	1	5	Right Occ			5/ 6/30	0	6					
6/ 6/30	$\begin{vmatrix} 2 \\ 1 \end{vmatrix}$	4	-			5/ 7/30	0	6					
6/7/30	1	5	RETES	STED		5/ 8/30	$\begin{array}{c} 0 \\ 0 \end{array}$	6					
6/10/30	0	6	11/29/30	0	3	5/ 9/30 5/10/30	0	6					
6/11/30	0	6	12/ 6/30	0	6	5/10/30	0	6					
6/14/30	0	0	12/ 8/30	0	6	6/10/30	0	6					
			12/ 9/30	0	6	0/10/00	U	U					
			12/10/30	0	6								
			12/11/30	0	6								
			12/12/30	0	6								
			12/13/30	0	6								
			1/ 3/31	0	6								
			2/ 7/31 3/ 2/31	0	6								

APPENDIX C Records in water tank

			necoras in	water t	<u>шпк</u>			
	4 TESTED			7 STED		9 TESTED		
Date	Re	sult	Date Result Date				Rei	sult
Date	R	L	Date	R	L	Date	R	L
5/ 1/30	4	2	4/ 8/30	1	5	4/11/30	4	2
5/ 2/30	4	2	4/ 9/30	0	6	4/12/30	5	1
5/ 3/30	3	3	4/10/30	0	6	4/14/30	5	1
5/ 5/30	3	3	4/11/30	0	6	4/15/30	4	2
5/ 6/30	2	4	4/12/30	0	6	4/17/30	2	4
5/ 7/30	4	2	4/14/30	0	6	4/18/30	1	5
5/ 8/30	4	2	4/15/30	0	6	4/19/30	3	3
Operated 5/12 Left Frontal thetic		maes-	Operated 4/Right Front			Operated 4, Right Fron		
RETE	ESTED		RET	ESTED		RETI	ESTED	
6/ 3/30	4	2	5/12/30	0	6	5/12/30	4	2
6/ 4/30	5	1	5/13/30	0	6	5/13/30	3	3
6/ 5/30	5	1	5/14/30	0	6	5/14/30	3	3
6/ 6/30	4	2	5/15/30	0	6	5/15/30	3	3
6/ 7/30	4	2	5/16/30	0	6	5/16/30	4	2
6/10/30	3	3	5/17/30	0	6	5/17/30	4	2
6/11/30	2	4	5/19/30	0	6	5/19/30	5	1
TES		<u> </u>		8 STED	,		l6 STED	
		sult			sult	Result		
Date	R	L	Date	R	L	Date	R	L
4/28/30	1	5	4/ 7/30	4	2	4/ 7/30	6	0
4/29/30	4	2	4/ 8/30	4	2	4/ 8/30	5	1
4/30/30	2	4	4/ 9/30	1	5	4/ 9/30	4	2
5/ 1/30	1	5	4/10/30	5	1	4/10/30	6	0
5/ 2/30	2	4	4/11/30	5	1	4/11/30	5	1
5/ 3/30	1	5	4/12/30	4	2	4/12/30	5	1
5/ 5/30	3	3	4/14/30	5	1	4/14/30	6	0
_	Operated 5/12/30 Right Frontal			21/30 al		Operated 4/21/30 Left Somaesthetic		
RETE	STED		RET	ESTED		RET	ESTED	
6/ 3/30	1	5	5/12/30	5	1	5/12/30	5	1
6/ 4/30	1	5	5/13/30	4	2	5/13/30	5	1
6/ 5/30	3	3	5/14/30	5	1	5/14/30	5	1
6/ 6/30	2	4	5/15/30	5	1	5/15/30	2	4
6/ 7/30	0	6	5/16/30	5	1	5/16/30	2	4
6/10/30	2	4	5/17/30	5	1	5/17/30	1	5
	2	4	5/19/30	6	0	5/19/30	4	2

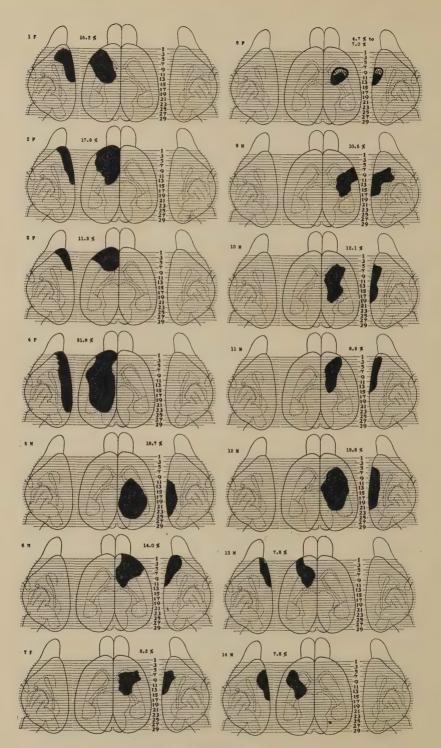
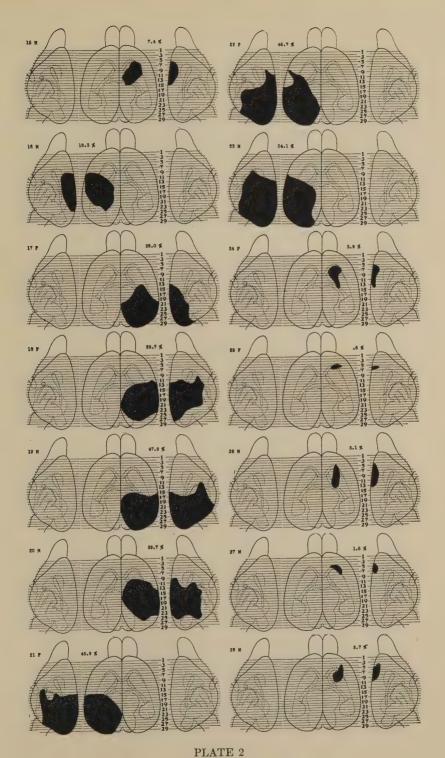


PLATE 1



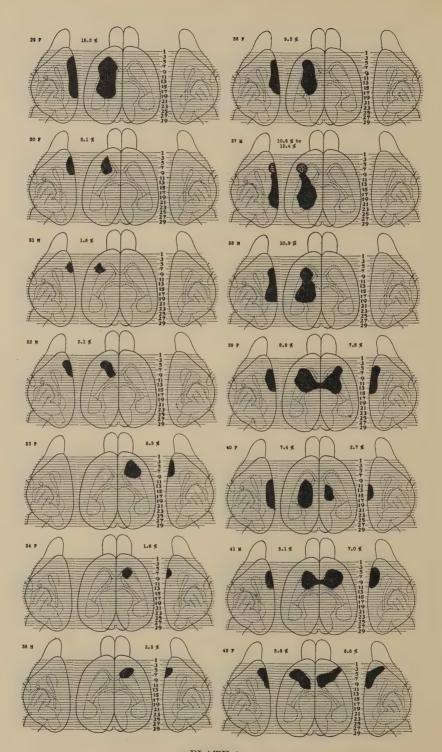


PLATE 3

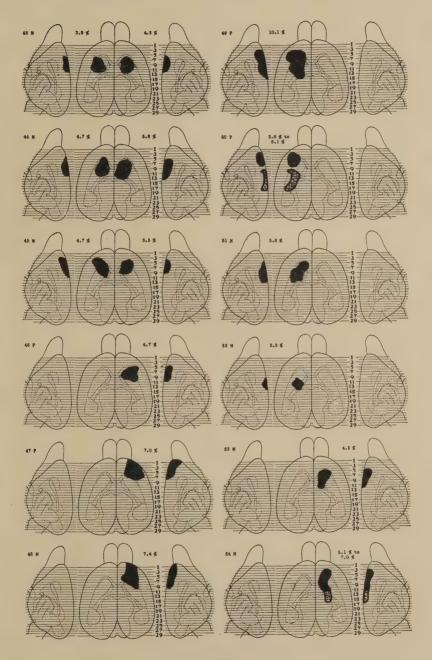
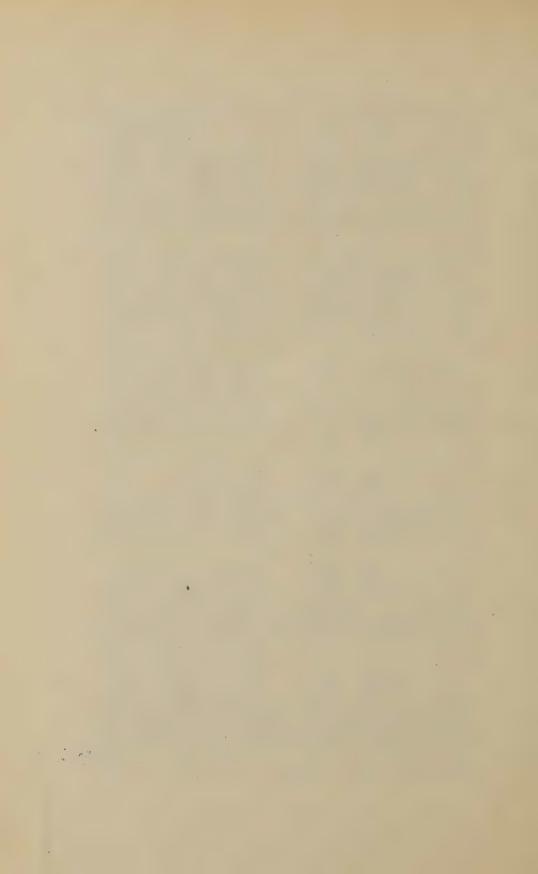


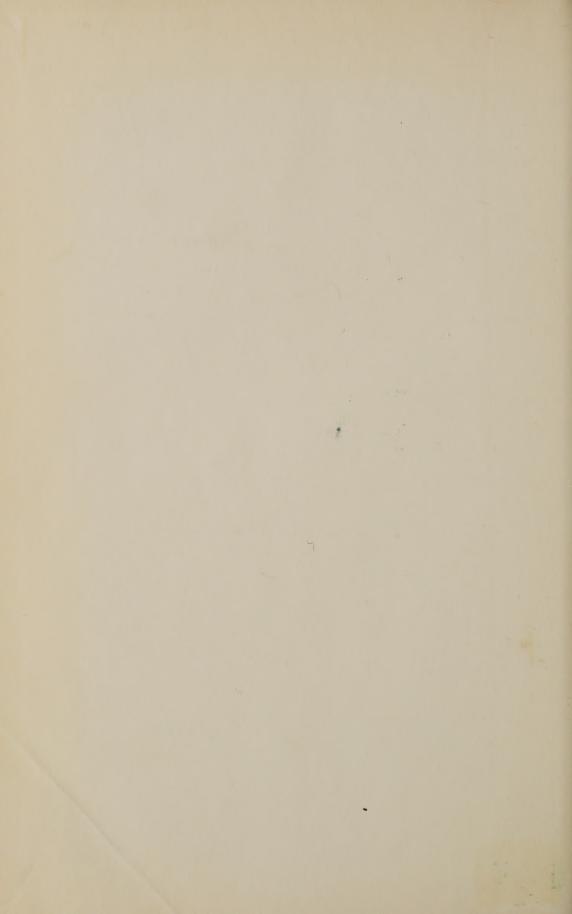
PLATE 4











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